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THERMAL PROTECTION SYSTEM REPAIR KIT PROGRAM

Contract No. NAS 9-15970

DRL No. 2

General Electric Company
Re-entry and Environmental Systems Division
3198 Chestnut St.
Philadelphia, PA 19101

28 November 1979

Final Report

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Prepared for

NASA
Johnson Space Center
NASA RD 1
Houston, Texas 77058

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

PREFACE

This document is the final report on the Thermal Protection System (TPS) Repair Kit Program. The program was performed under Contract NAS 9-15970 which was sponsored and directed by the NASA Johnson Space Center, Houston, Texas.

The program was managed and performed by the General Electric Company - Re-Entry and Environmental Systems Division (RESD), Phila., PA for NASA-JSC, in response to their request for developing a repair material, dispenser, and storage container to repair Space Shuttle tiles in orbit.

SUMMARY

The results of this program have provided very significant substantiation of the overall in-orbit tile repair approach being pursued by NASA Johnson Space Center. The major elements of the repair approach have been shown to be possible and prototype functional designs have been established which will insure that flight units can be delivered by May 1980.

The specific major results of this study were as follows:

- Material solutions for both small and large area repair
- Selection and substantiation of a mature, fully developed, pre-cured ablator - ESM 1004AP
- Formulation and substantiation of cure-in-place materials and selection of a specific material - RTV-577E
- Cure-in-place material vacuum and temperature cure characteristics consistent with in-orbit repair environments and with necessary working and cure times
- Selection of a specific dispenser approach with the following characteristics:
  - Pneumatic operation
  - No electrical power required
  - Astronaut physical effort minimized; handles only hose, valve and nozzle
  - Mixing reliability; i.e., if material flows it must be mixed in proper ratio to insure curing
- Extensive maturity of dispenser by design and development tests including:
  - Mockup
  - Functional breadboard and test
  - Functional prototype and test
  - KC-135 zero-g test

- Conceptual verification of storage containers including:
  - Packaging
  - Weight and volume
  - Thermal Control
- Verification of operational repair procedures
  - Moldline control
  - Pre-cured ablator provisioning and utilization
  - Special tools
  - Reflects astronaut constraints

1.0 INTRODUCTION

The work described in this report was performed to investigate feasibility and conceptual design aspects of repair materials and procedures for in-orbit repair of the Space Shuttle Orbiter TPS tiles. The program was an 11-week program with parallel tasks to investigate pre-cured ablators, cured-in-place ablators, cured-in-place ablator dispensers and repair kit storage containers. The work also reflects many interfaces with NASA-JSC to establish operational and test requirements for the overall repair concept. The output of this study forms the basis for continuation into final ~~application,~~ design, test, fabrication, flight training and flight utilization of the repair kit.

2.0 PROGRAM SCOPE

The program was directed toward conceptual feasibility of the in-orbit tile repair approach as established by NASA-JSC. The repair concept involved the following:

a. repair of partial or single tiles (6 x 6 inches) using a cure-in-place ablator

b. repair of multiple tiles (up to 18 x 36 inches) using a pre-cured ablator borded with the cure-in-place ablator material

c. utilization of a mixer-applicator (caulking gun) to catalyze, mix, and dispense the cure-in-place material.

The following tasks were performed to evaluate the feasibility of these repair procedures and to select materials and preliminary designs. Since a number of suitable materials were thought to be available for use as a pre-cured ablator, the primary effort was directed toward the cure-in-place material and related storage, dispensing, and cure problems.

The specific tasks were:

a. Select, substantiate, and provide a data package for a pre-cured ablator material.

b. Perform material studies to investigate cure-in-place materials including:

   1. Catalyst and cure studies

   2. Material formulations for suitable bonding, viscosity, ablation, and other performance characteristics

   3. Ablation test and evaluation

   4. Perform property testing for critical properties such as bond strength to various substrates, vacuum effects, temperature effects and thermal aging

   5. Selection of material and alternates

   6. Support mixing and applicator design

c. Perform conceptual evaluation and design of mixer-applicators including:

   1. Concepts and trade off

   2. Selection of primary approach

3. Breadboard design, fabrication and evaluation

4. Conceptual design of prototype units, including small single part (and large three-part)* units

d. Perform assessment of storage container and other tools required for the total repair kit including:

1. Storage container packaging and conceptual design

2. Thermal control problem assessment

3. Special tools for performing repairs

e. Prepare and deliver 10 pounds of selected pre-cured ablator and cure-in-place material.

The above tasks were successfully accomplished and the results are reported in Section 4.0.

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*The large three-part unit design evaluation was specified by program change during the 7th week of the program.

Intentionally Omitted

4.0 STUDY RESULTS

4.1 REQUIREMENTS SUMMARY

The basic requirements for the development of the repair kit were provided by the initial statement of work. The requirements were further detailed and modified by supporting documentation such as early versions of NASA-JSC 16209 and other technical data derived from presentations, interface meetings, and telecommunications. NASA-JSC 16209, "TPS Repair Kit Requirements Document" was the basic requirements reference and provided the guidelines for the study program. The major driving requirements are summarized as follows:

a. Ablation performance to maintain maximum structure temperature of 350°F during re-entry

b. Bond strengths greater than 40 psi to RTV-560 surfaces or surfaces with residual RTV-560, and greater than 6.5 psi to RSI surfaces

c. Cure characteristics to assure adequate strength and ablation prior to re-entry yet allow sufficient working life during application

   1. original requirement - gel in 15-30 min
      - cure in 18-24 hours

   2. updated requirements - working life of one hour
      - cure in 18-24 hours

   3. vacuum environment (10^{-5} torr) at various repair area temperatures
      - structural surfaces 20 to 100°F
      - SIP/RSI surfaces -10 to 120°F

d. Simple application to meet moldline and astronaut constraints

   1. 0.25-inch maximum moldline variation

   2. cure-in-place material to be used to bond pre-cured materials

   3. minimum astronaut forces for mixing and application

   4. flow rate 5 - 20 in^3/min (derived requirement to support typical repair missions)

   5. derived effective viscosity of 3000 to 8,000 poises for application effectiveness

e. Storage container and materials requirements

1. Maximum volume 12 ft^3

2. Maximum weight 300 lbs

3. 1080 in^3 cure-in-place material

4. 6480 in^3 pre-cured material

5. Thermal control as required for applications and cure

4.2 PRE-CURED ABLATOR

4.2.1 TRADE OFF, SELECTION AND DATA PACKAGE

Task Objective

The objective was to provide: 1) trade offs leading to the selection of ESM 1004AP as the recommended pre-cured ablator, 2) a concise description of the selected pre-cured ablator, and 3) thermal and physical properties of ESM 1004AP.

Space Shuttle Ablator Requirements

Previous studies conducted by GE-RESD to evaluate the candidate ablator thermal protection requirements resulted in design charts being developed for specific shuttle missions. Typical results of this study are shown in Figures 1 and 2, which depict the ablator thickness and unit weight as a function of cold wall heat flux for both ESM 1004AP and 1004X. ESM 1004X was considered with a thin RTV-560 coating.

The design curves are shown for two heating times, 1000 and 3000 seconds, which were for two missions that were being evaluated at that time, a low and high cross range mission. It can be seen in Figure 1 that the ESM thicknesses increase with heat load and heating time and that the thickness requirements of ESM 1004X is almost double that of ESM 1004AP. However, Figure 2 shows that ESM 1004X is considerably lighter than ESM 1004AP. For all of these calculations, the maximum structure temperature allowable was assumed to be 300°F.

Figure 3 shows the predicted thickness requirements for ESM 1004AP and 1004X for the current design mission, which has a heating time of 1650 seconds. Also included in the figure are current RSI tile thicknesses for several locations on the space shuttle obtained from NASA-JSC. The tile thicknesses are faired values and not necessarily the design thickness requirement. Also the current design criteria is a maximum allowable structure temperature of 350°F. From this limited data, it can be concluded that the RSI tiles can be replaced in all locations (for which we have tile thicknesses defined) by an equal thickness of ESM 1004AP to provide the necessary thermal protection.

Also shown in Figure 3 are some recent NASA-JSC calculations for ESM 1004AP using thermophysical properties provided by GE-RESD. These results are in general agreement with the design curve and differences can be attributed to large variations in the structural thickness employed in the calculations. Finally, Figure 4 shows the unit weights of the ablators and RSI for the current design mission.

The supporting thermo-physical data used in these analyses is attached as Tables 1 through 3, and Figure 5.

ESM 1004AP Description

General Electric Re-Entry and Environmental Systems Division (GE-RESD) has, over a period of years, developed a family of flight proven Elastomeric Shield Materials (ESM) which have had broad application for space and re-entry vehicle thermal protection.

The ESM 1004 series of elastomeric foams are based upon RTV-560 and can be fabricated at density levels from ~12 PCF to ~90 PCF. They are prepared by a chemical foaming process and are reinforced with up to 13 weight percent of inorganic fibers. As a result, they are flexible in the virgin state and form strong, coherent chars as a result of ablation. These materials have been fabricated in honeycomb as well as in the unsupported state.

ESM 1004AP is the prime material in the 1004 series, with a density of 35 ± 3 PCF and is provided as an unsupported (non-honeycomb) flexible ablator.

ESM 1004AP Properties

In addition to those thermophysical properties listed in Tables 1 through 3 and Figure 5, additional mechanical and optical properties are available as shown in Table 4, and Figures 6 through 11.

ESM 1004AP Manufacturing Flow Plan

A schematic flow plan of the GE proprietary ESM-1004AP is shown as Figure 12.

ESM 1004 AP Specimens

ESM 1004-AP specimens were provided 10/18/79 to NASA-JSC. That material is identifiable as follows:

1 piece, approximately 6" x 12" x 0.6" : LOT WG 591A1
1 piece, approximately 6" x 6" x 0.9" : LOT WG 590A1

The contractually required 10 pounds of ESM was specifically fabricated and delivered. The material was prepared as LOT ZL218A1. Acceptance data on the material was:

ρ 36 lb/ft^3

Tensile 90 psi

TABLE 1. THERMAL PROPERTY DATA USED IN THE ESM 1004X AND ESM 1004-AP REKAP MODELS

PROPERTY	ESM 1004 X	ESM 1004 AP
DENSITY, VIRGIN, PCF	15	36
DENSITY, CHAR, PCF	6	14.4
THERMAL CONDUCTIVITY	FIG. 5	FIG. 5
SPECIFIC HEAT	TABLE 2	TABLE 3
HEAT OF GAS FORMATION	TABLE 2	TABLE 3
SPECIFIC HEAT OF PYROLYSIS GAS	TABLE 2	TABLE 3
SURFACE EMISSIVITY	0.80	0.80
ARRHENIUS PARAMETERS.		
Z_1, SEC^{-1}	15000	30000
ORDER OF REACTION	2	2
E_1, BTU/LB MOLE	44,700	47,500
CHAR PARAMETERS:		
N_1	1.0	1.0
$C_1\left(1-\frac{K_c}{K_v}\right)$	-2.25	-1.34
N_2	1.0	1.0
C_2	0	0

TABLE 2. ESM 1004X REKAP MODEL DATA

T °R	Hgf BTU/LBM	C_p BTU/LBM °R	K BTU/FT SEC °R
1	50	0.001	0.55×10^{-5}
250	↓	0.18	0.75
500		0.29	1.05
600		0.31	1.18
700		0.332	1.35
800		0.355	1.55
900		0.378	1.8
1000		0.398	2.0
1250		0.4	2.24
1500	45	↓	2.43
1750	12[illegible]		2.65
2000	2730		2.87
2250	2960	0.46	3.12
2500	3050	0.55	3.39
2750	3120	0.643	3.68
3000	3165	0.725	3.99
3250	3200	0.805	4.32
20000	↓	↓	↓

TABLE 3. ESM 1004-AP SPECIFIC HEAT AND HEAT OF GAS FORMATION USED IN THE REKAP MODEL

TEMPERATURE °R	SPECIFIC HEAT BTU/LB - °R	HEAT OF GAS FORMATION BTU/LB	SPECIFIC HEAT OF GAS BTU/LB - °R
0.	0.1000E 02	0.5000E 02	0.3840E 00
0.2100E 03	0.1080E 00	0.5000E 02	0.3840E 00
0.4600E 03	0.2350E 00	0.5000E 02	0.3840E 00
0.6100E 03	0.3130E 00	0.5000E 02	0.3840E 00
0.6600E 03	0.3380E 00	0.5000E 02	0.3840E 00
0.7100E 03	0.3650E 00	0.5000E 02	0.3840E 00
0.7600E 03	0.3900E 00	0.5000E 02	0.3840E 00
0.8600E 03	0.4290E 00	0.5000E 02	0.3840E 00
0.1210E 04	0.4400E 00	0.5000E 02	0.3840E 00
0.1335E 04	0.4400E 00	0.5000E 02	0.3840E 00
0.1460E 04	0.4400E 00	0.4500E 03	0.3840E 00
0.1710E 04	0.4400E 00	0.1000E 04	0.3840E 00
0.1960E 04	0.4400E 00	0.2610E 04	0.3840E 00
0.2075E 04	0.4400E 00	0.2820E 04	0.3840E 00
0.2210E 04	0.4600E 00	0 2950E 04	0.3840E 00
0.2315E 04	0.4850E 00	0.3020E 04	0.3840E 00
0.2900E 04	0.6950E 00	0.3160E 04	0.3840E 00
0.3460E 04	0.8700E 00	0.3200E 04	0.3840E 00
0.4460E 04	0.8700E 00	0.3200E 04	0.3840E 00
0.1000E 05	0.8700E 00	0.3200E 04	0.3840E 00

TABLE 4. ESM 1004-AP PROPERTIES

<u>BOND SHEAR STRENGTH</u>	75°F	75 PSI
SHIELD/BOND SYSTEM	300°F	47
(ESM/RTV-560/BE)	500°F	31
<u>OPTICAL</u>		
SOLAR ABSORPTANCE		~ 0.75
TOTAL HEMISPHERICAL EMITTANCE		0.85
α/ϵ_H RATIO		~ 0.88
<u>RF TRANSMISSION</u>		
R.T. DIELECTRIC CONSTANT		1.70 - J0.016
LOSS TANGENT		0.009
ATTEN. COEFF. CM^{-1}		0.01229
MAX. CHANGE IN SIGNAL TRANSMISSION		
HEATING		-0.4 DB
COOLING		0.2 DB

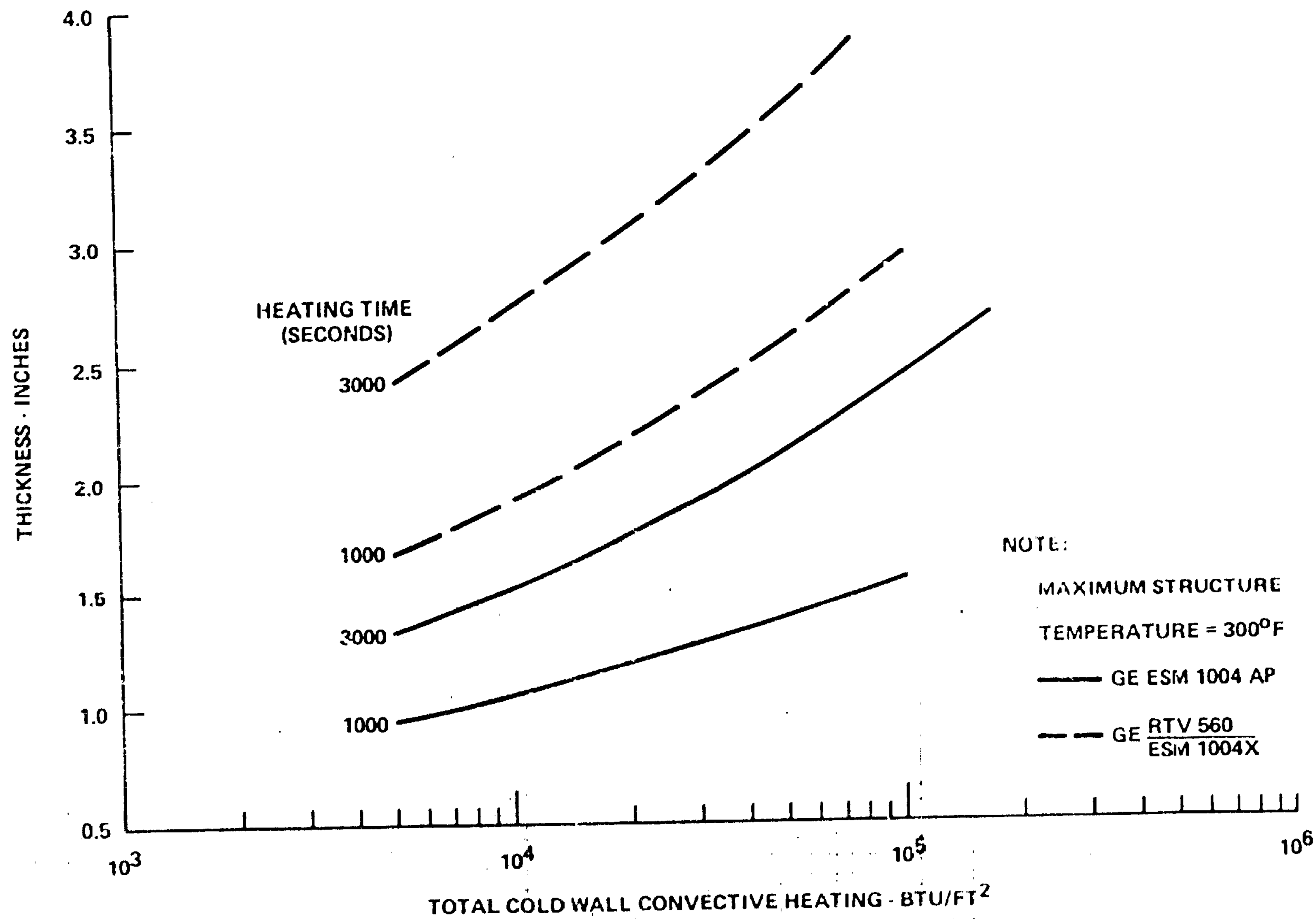

Figure 1. Thermal Protection Requirements for Space Shuttle

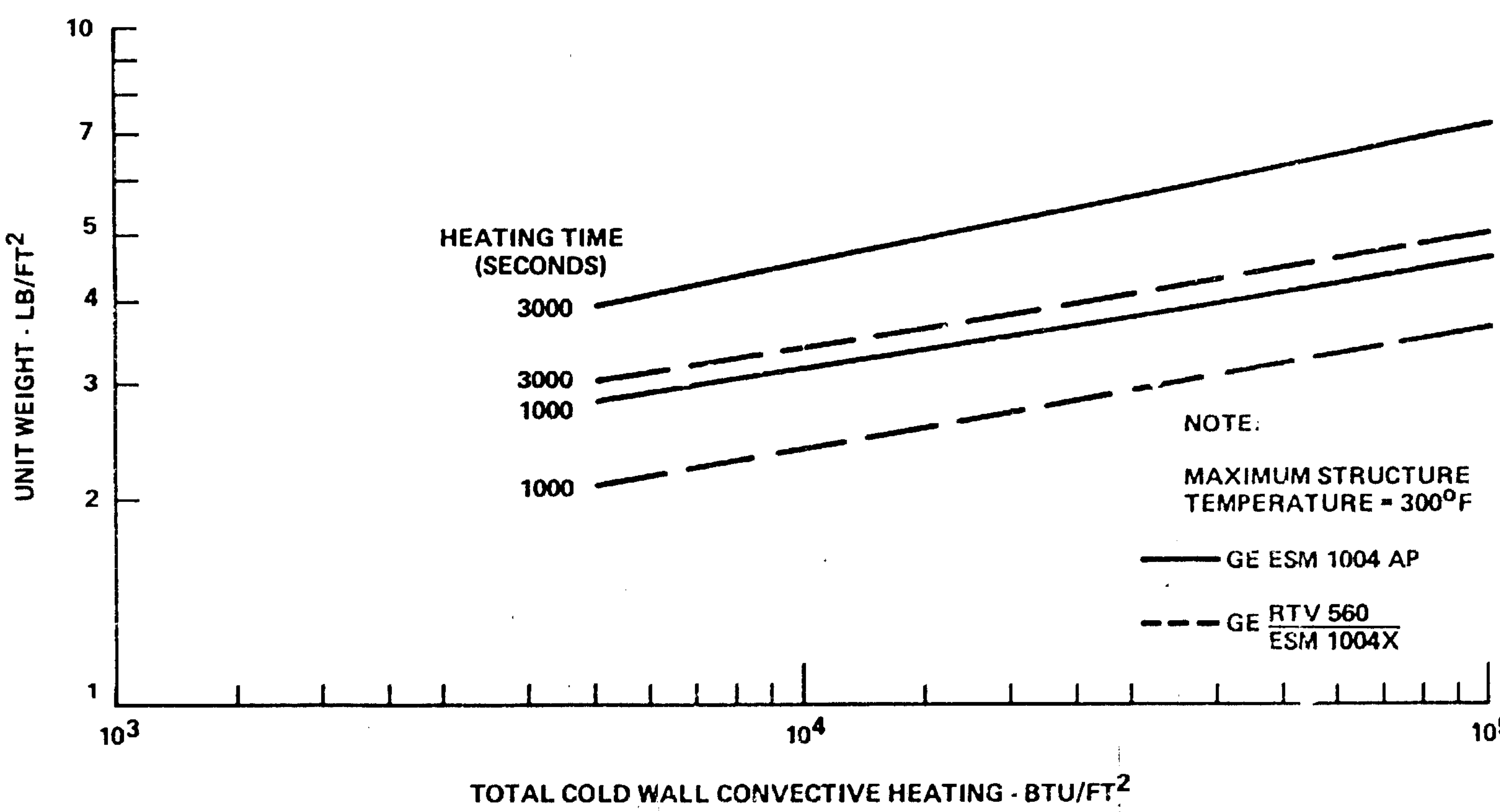

Figure 2. Thermal Protection Requirements for Space Shuttle

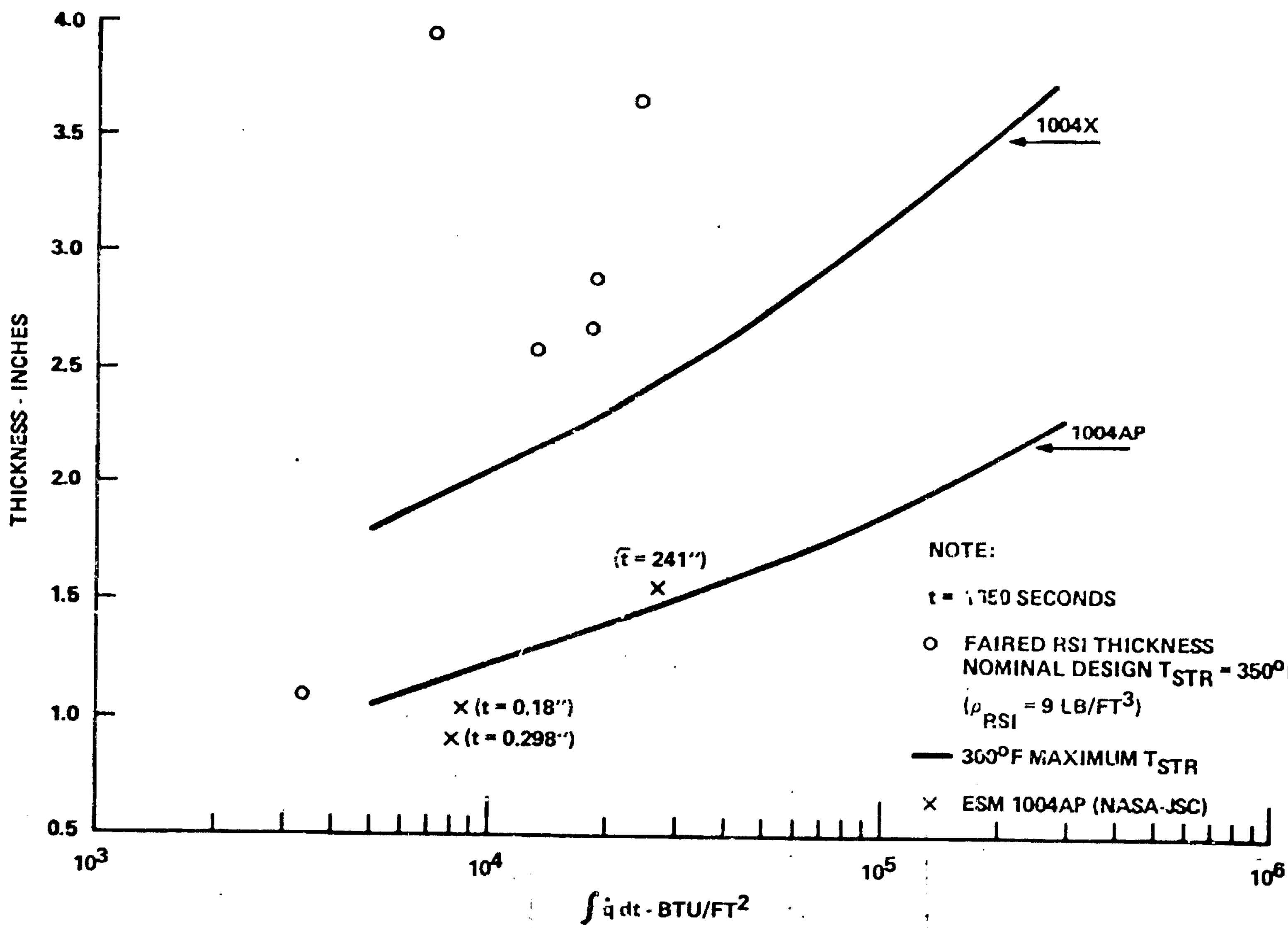

Figure 3. Comparison of Ablator & RSI TPS Requirements for Space Shuttle

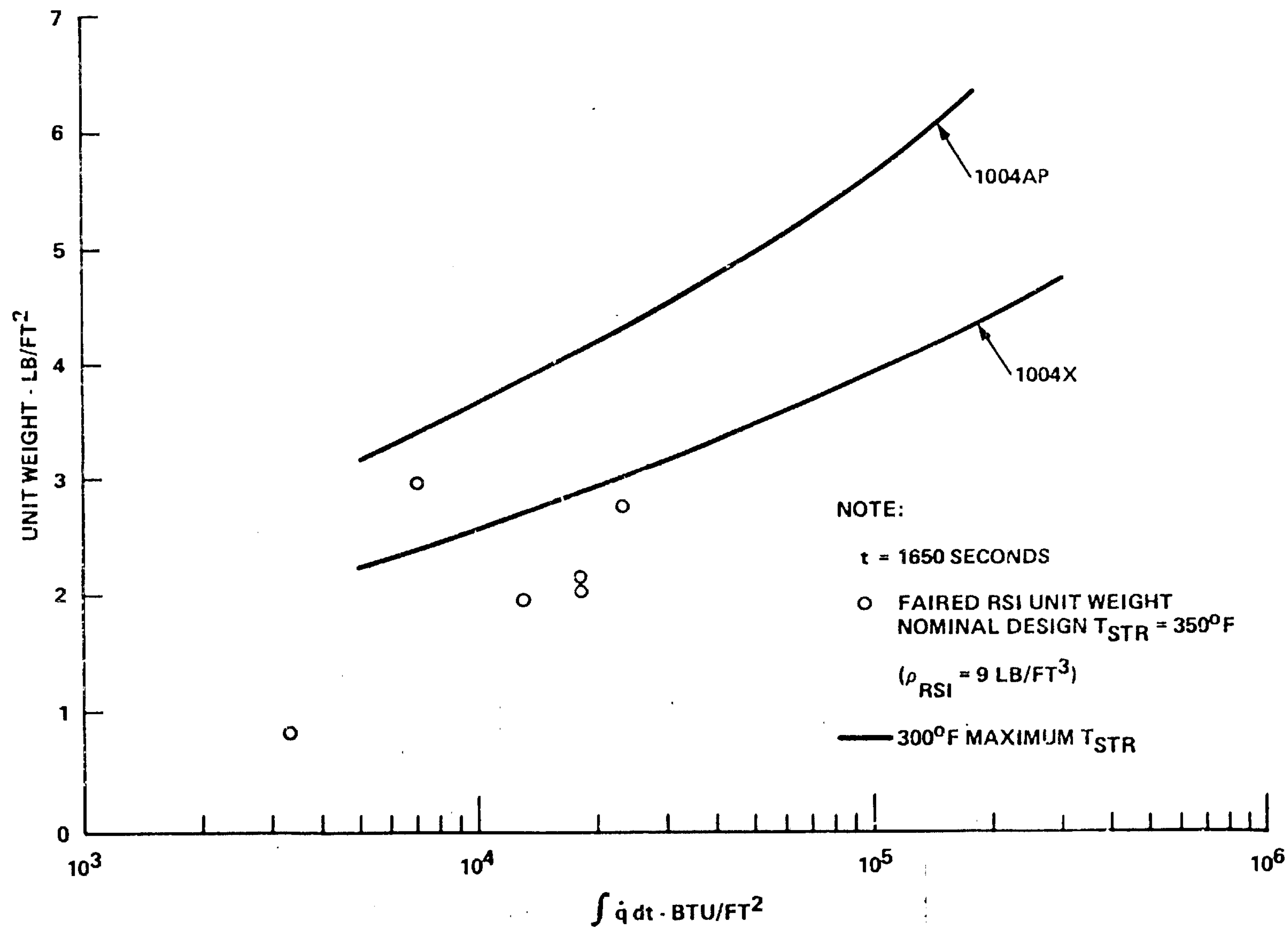

Figure 4. Comparison of Ablator & RSI TPS Requirements for Space Shuttle

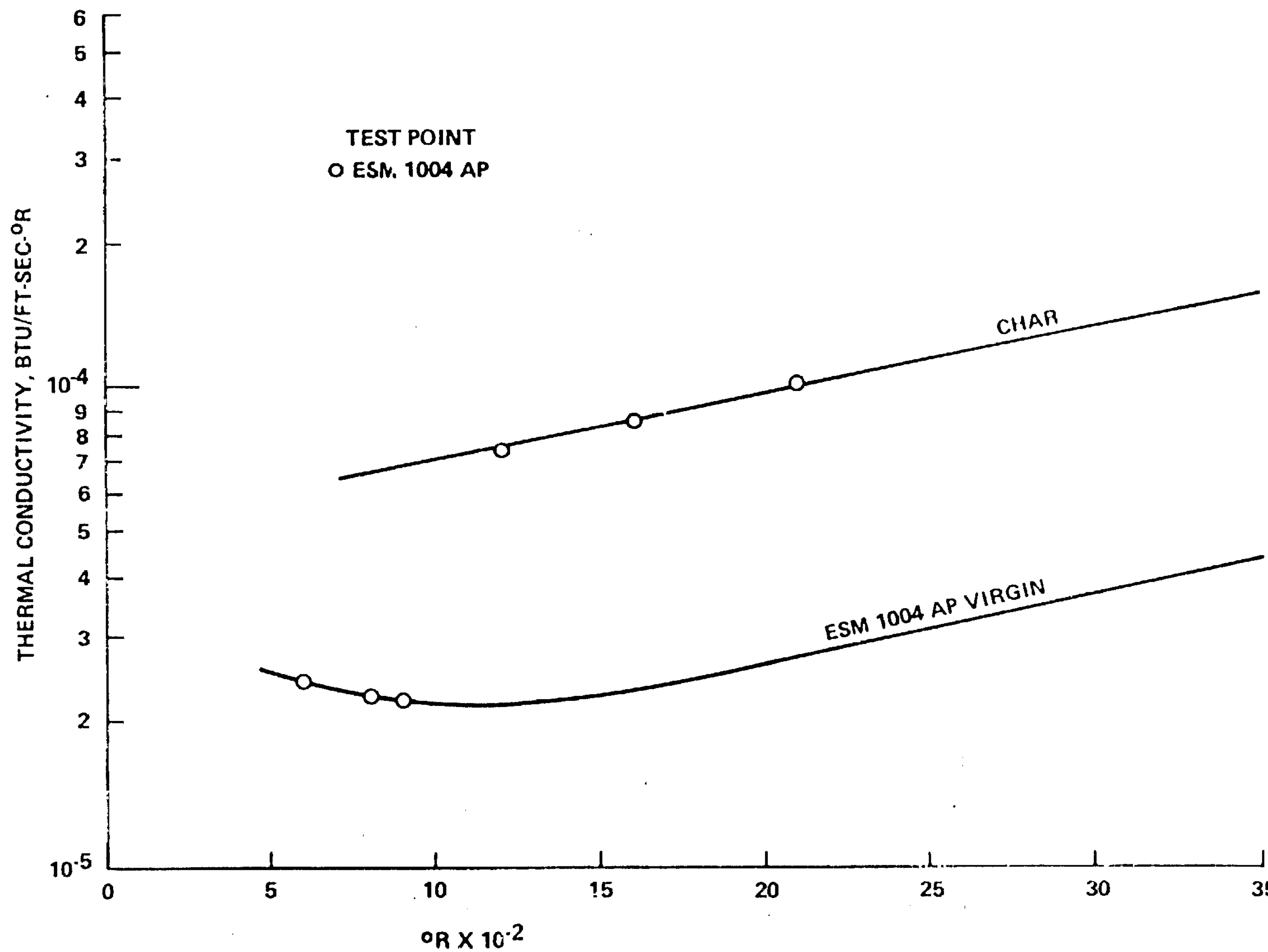

Figure 5. Thermal Conductivity vs. Temperature

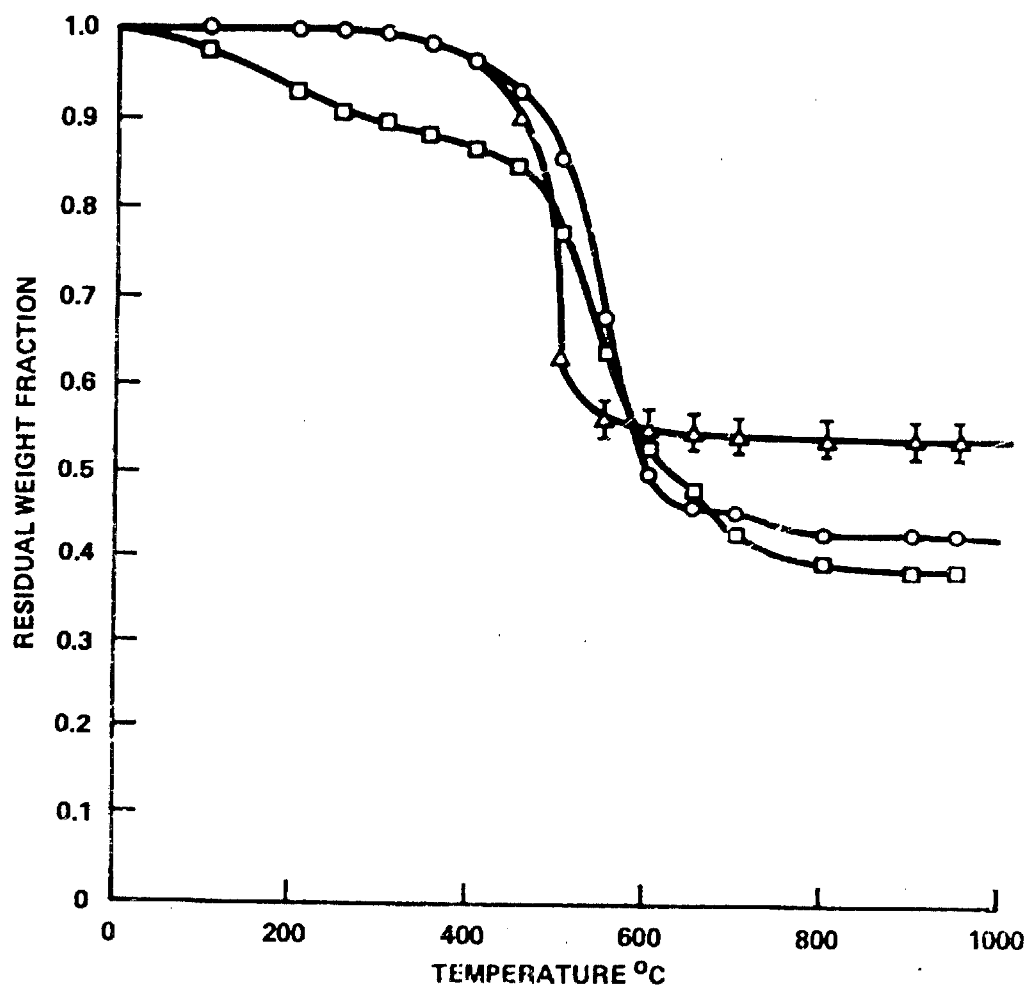

Figure 6. TGA of ESM 1004AP

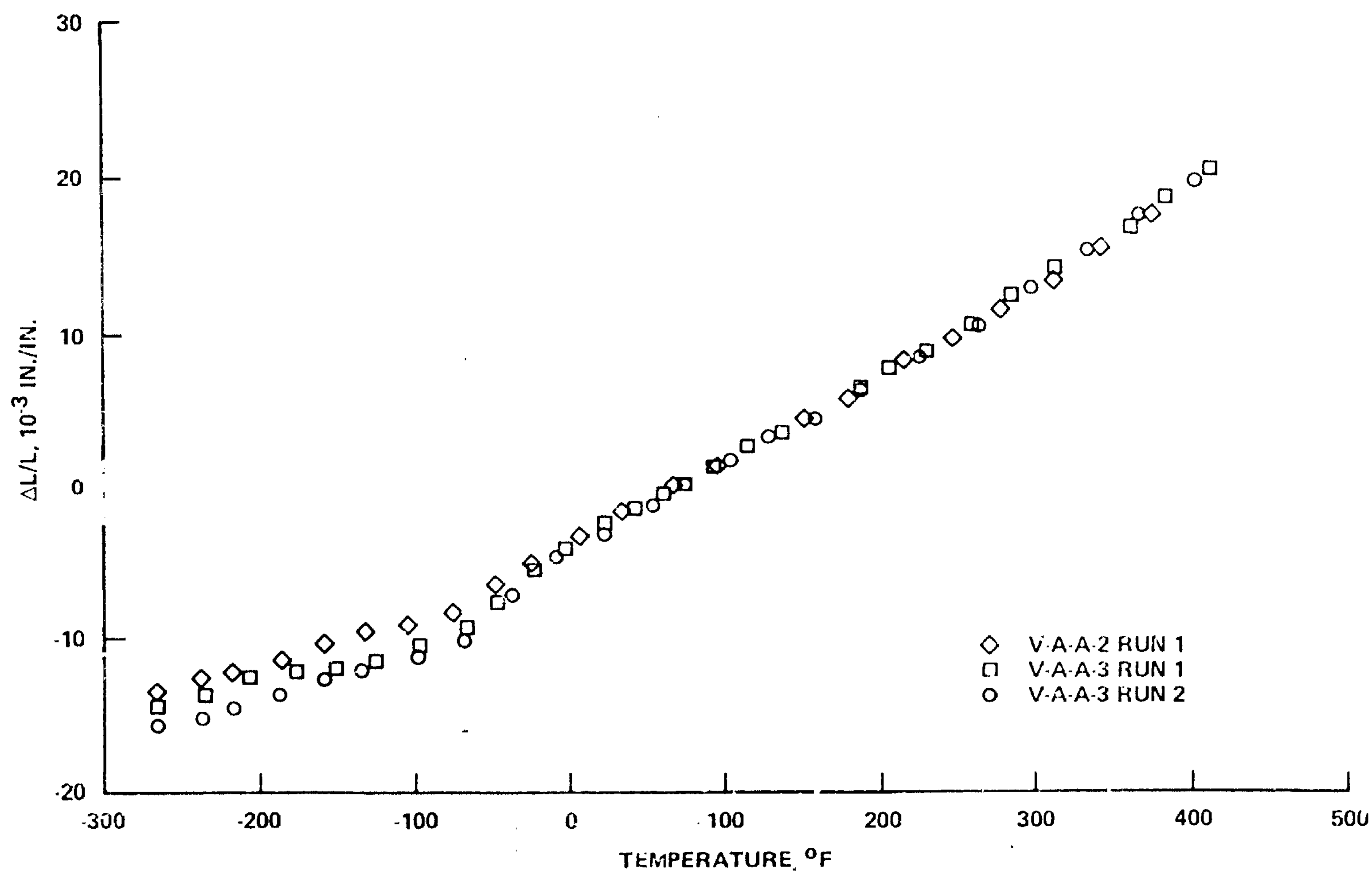

Figure 7. Thermal Expansion of ESM 1004-AP (Virgin Material)

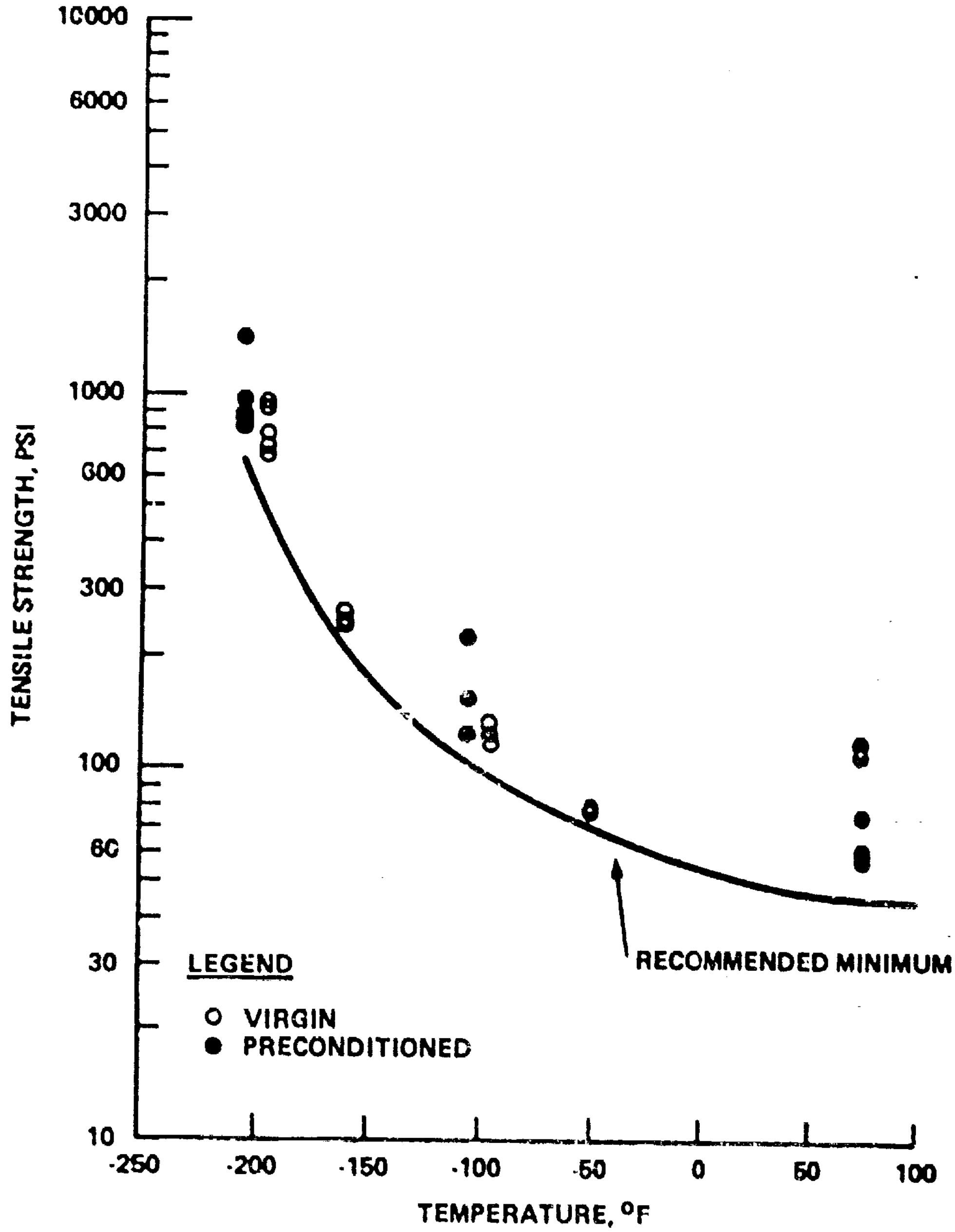

Figure 8. Tensile Strength of ESM 1004-AP

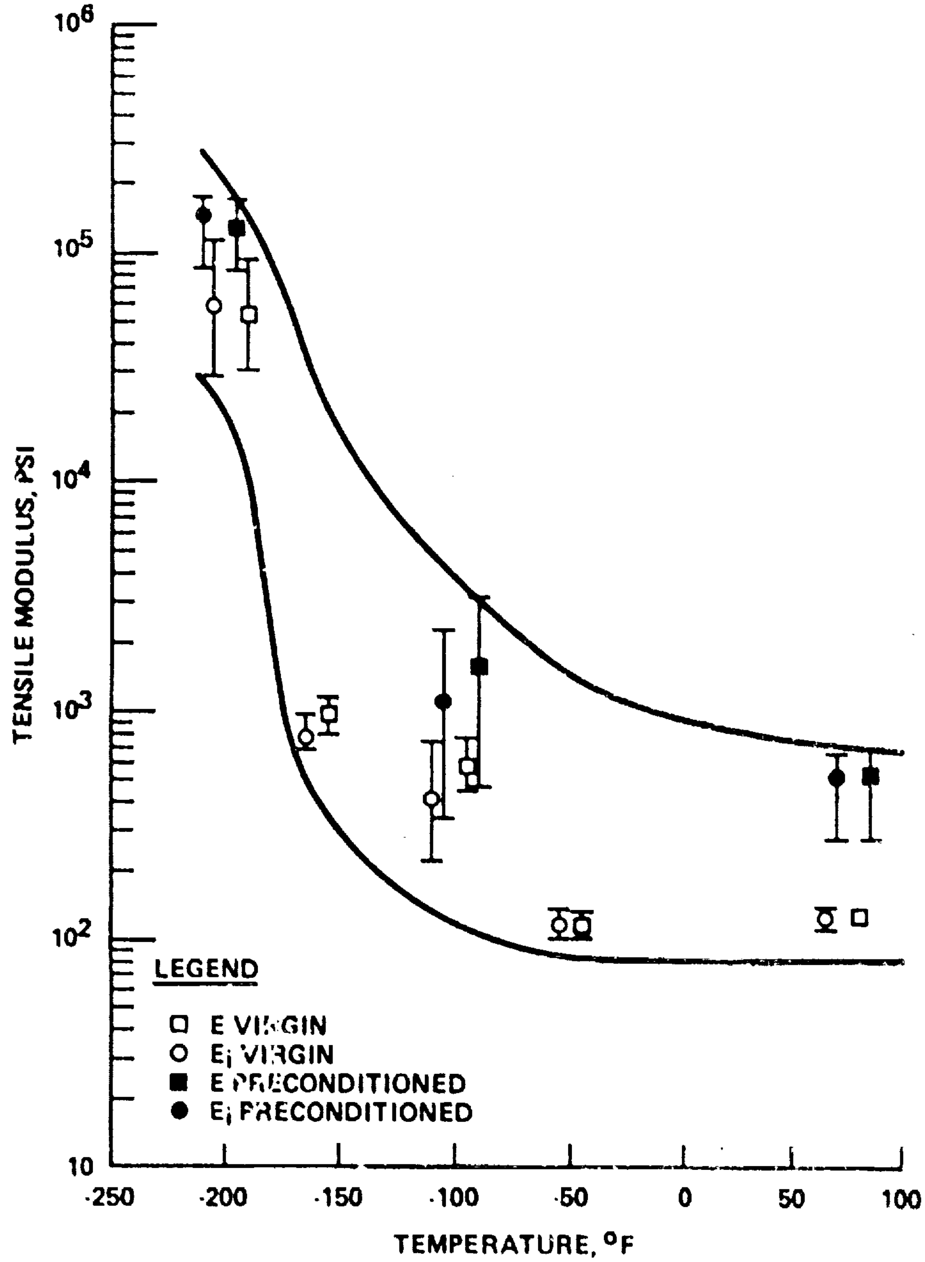

Figure 9. Tensile Modulus of ESM 1004-AP

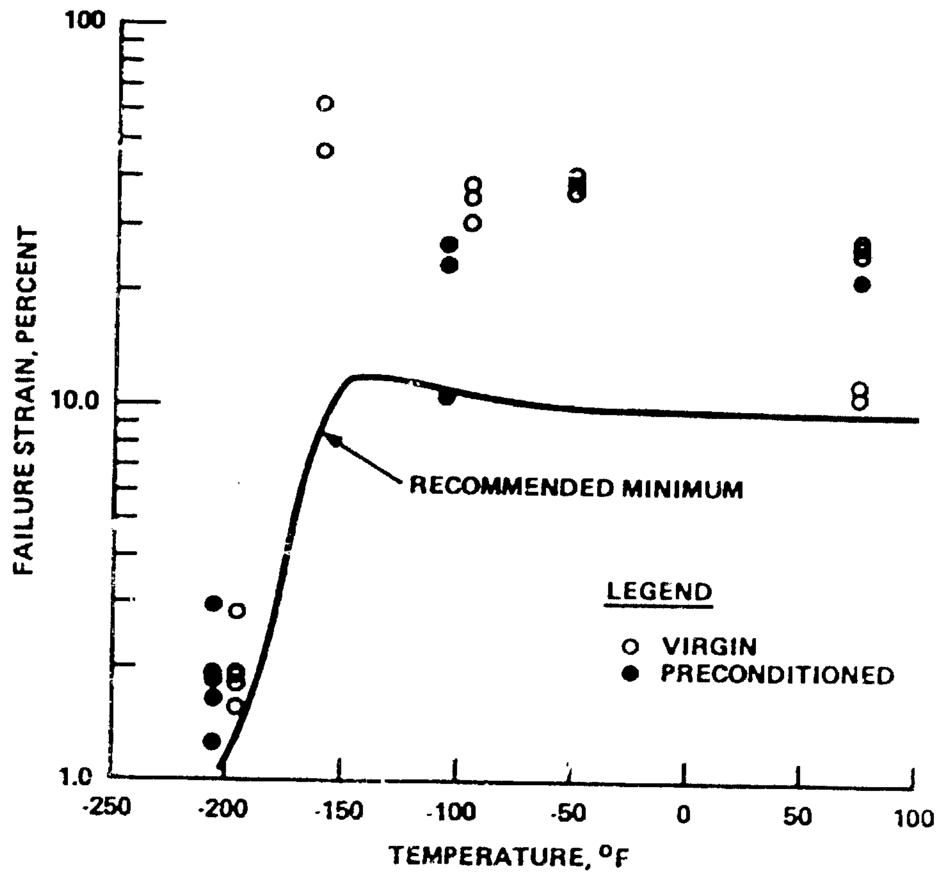

Figure 10. Failure Strain of ESM 1004-AP

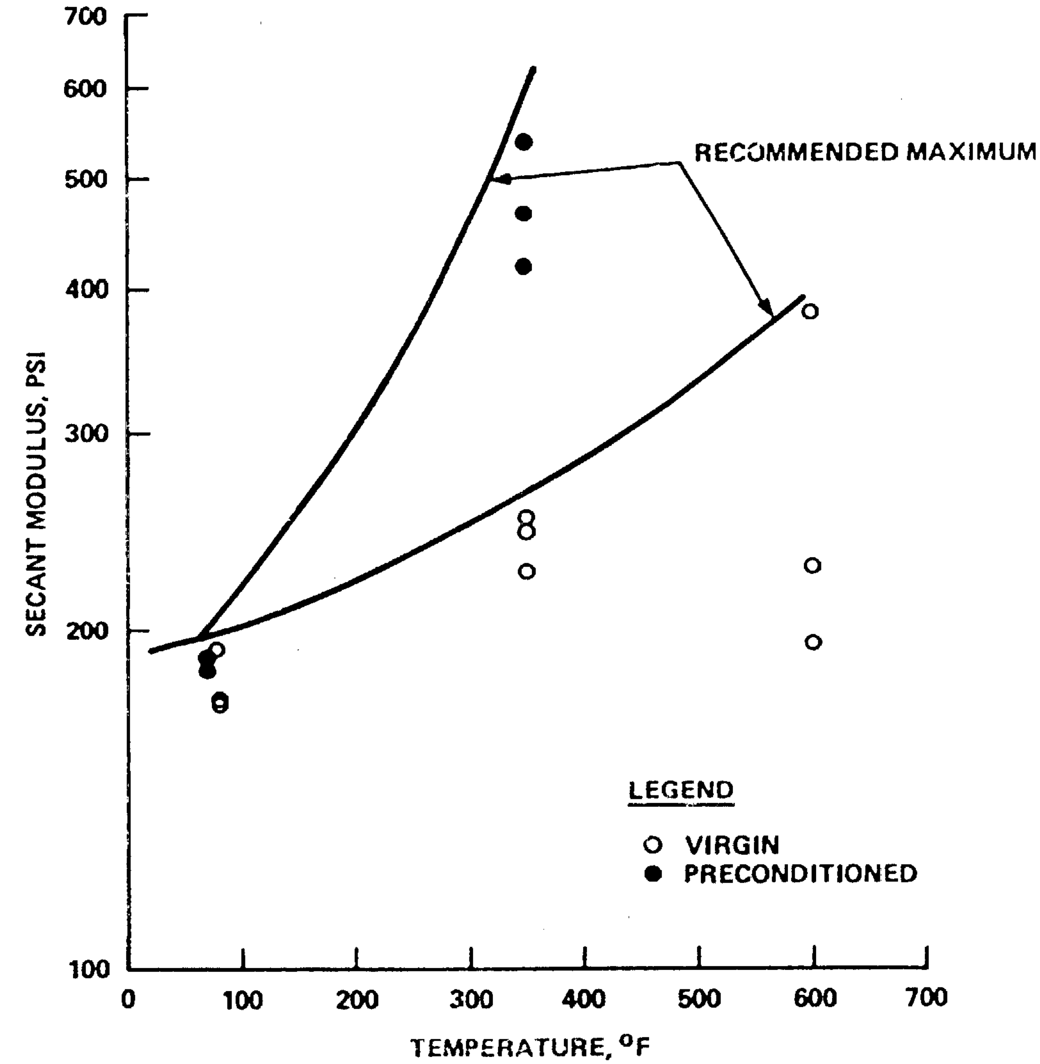

Figure 11. Compressive Secant Modulus of ESM 1004-AP

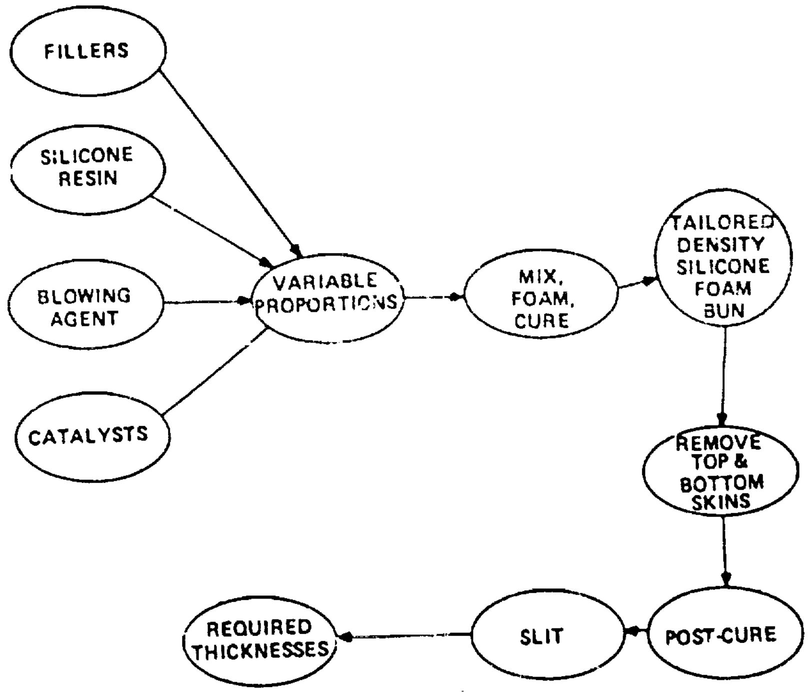

Figure 12. ESM Manufacturing Flow Plan

4.2.2 PRECURED ABLATOR MATERIAL STORAGE AND UTILIZATION

Summary

Preliminary studies suggest that supplying the required quantity of precured ESM ablator in an assortment of thicknesses provides the astronaut wide flexibility in repairing damaged areas which can range from 6 x 6 inches to 18 x 36 inches with the depth from a few tenths to 4 inches. The recommended assortment arising from the studies detailed in this section consists of 54 two-inch tiles, forty - 1 1/4-inch tiles and thirty - 3/4-inch tiles with each tile being 6 x 6 inches. The total volume recommended meets the 3.75 ft^3 defined in the requirements document. These tiles may be supplied in prescored slabs measuring 12 x 12 inches and/or 12 x 18 inches.

Requirements

The quantity requirements given in the specification of 3.75 ft^3 of precured ablator is sufficient to fill five cavities of 18 x 36 x 2 inches deep. The thicknesses of HRSI and LRSI tiles range from 0.3 to 4 inches. The material selected (ESM 1004-AP) is discussed in Paragraph 4.2.1.

Approach

The above requirements were analyzed and the following conclusions reached:

a. Areas less than 3/4-inch thick will be filled (repaired) with cure-in-place ablator.

b. A tile equals an area of 6 x 6 inches and the cavity is totally empty (flight tile completely removed). Furthermore, we considered that the largest stock size of material which the astronaut could handle at the repair site was 12 x 12 inches or at best 12 x 18 inches.

Thickness

A tile thickness of 3/4-inch was selected as the thinnest stock to be supplied, which is compatible with the procedure stated above. Two inches (2") was also selected as the thickest material to be supplied, because it permits filling the deepest cavity with two layers of material.

The consequence of providing an intermediate thickness of either 1 or 1 1/4 inch was then examined. Figure 13 shows the number of layers or thickness required to fill cavities from 3/4 to 4 inches deep, in increments of 1/4 inch. For this analysis a zero thickness bondline was assumed. The cross-hatched portion indicates a cure-in-place layer 1/4-inch thick was needed to fill up the cavity. Examination of the Figure shows that if a 1-inch thickness is chosen, then there would be three cases in which three layers would be required, whereas if 1 1/4-inch is chosen, there is only one instance with three layers, although there are more cases requiring a make-up bed. But since there must always be a finite bond thickness, the "make-up bed" is not really a disadvantage. Therefore, 1 1/4-inch stock thickness was selected as the intermediate size to be provided. Another advantage is that the number of slabs of each thickness to fill one each of the cavities is 24, equally distributed (8 of each thickness).

Repair Area Size

The repair area ranges from 1 tile to 18 tiles 6 x 6 inches (or enough for 18 x 36 inches in plan form) and from 3/4 to 4 inches in depth. Since it is reasonable to assume that the damage will be random, a random numbers generator was exercised and five pairs of numbers representing area (as the number of tiles) and depth between the above limits were obtained. This simulation was repeated three times. Figure 14 depicts these five areas, and shows the corresponding depth of each cavity for the three cases of "missions" simulated. The number of tiles required to fill each cavity, by stock thickness was calculated. For Figure 14, the intermediate stock thickness was assumed to be 1 inch. Figure 15 shows the same cavities, but using 1 1/4-inch thickness. Table 5 summarizes and compares the number of tiles by size to fill the assumed cavities. It shows that using 1 1/4-inch size reduces the total number of tiles required, further reinforcing the selection of 1 1/4-inch stock as the better solution. Mathematically, 1 1/4-inch is approximately the geometric mean between 3/4 and 2.

Distribution of Tiles Supplied

In order to determine how to apportion the quantity of tiles to be supplied to make up the required 3.75 ft^3 volume, the mean and standard deviation of the tiles required for each of the three "missions" simulated was calculated. Various models can then be assumed to calculate the quantity of tiles:

a. Equal volumes

b. Equal number of tiles

c. X times the mean

d. The means + 4 times the standard deviation

Table 6 shows the mean and standard deviation of the quantity of tiles by thickness. It also shows the volume that would result if some of the models listed above were used. A preliminary selection was made of $\overline{X} + 2\sigma$ model, or a total of 4.3 ft^3. However, due to volume and weight constraints, the recommended provisioning was adjusted downward to just meet NASA's requirements as shown below.

	Mid-Term		Final Selection	
Tile Thick (in.)	Qty	Vol (ft^3)	Qty	Vol (ft^3)
2	58	2.42	54	2.25
1 1/4	48	1.25	40	1.04
3/4	38	0.59	30	0.47
Tot.	144	4.26	124	3.76

Note that the reduction in tile quantity was less for the 2-inch than for the others because the analysis had shown a larger variance, thus less certainty in the actual number needed.

TABLE 5. NUMBER OF TILES VS. AVAILABLE THICKNESS

	Total No. Tiles For Repair			
Case No.	1	2	3	
Slab Thick. (in.)				
3/4, 1, 2	79	102	76	
3/4, 1-1/4, 2	64	81	65	SELECTED

TABLE 6. MATERIAL VOLUME VS. SUPPLY MODEL

			Volume FT^3			
Tile Tk. (in.)	Mean	Std Dev	$3\bar{X}$	$\bar{X} + 1\sigma$	$\bar{X} + 2\sigma$	$\bar{X} + 3\sigma$
2	22	18	2.8	1.7	2.4	3.2
1 1/4	26	11	2.0	1.0	1.3	1.5
3/4	22	8	1.0	.5	.6	.7
TOTAL			5.8	3.2	4.3*	5.4

*SELECTED FOR STORAGE BOX ASSESSMENT (PRELIMINARY)

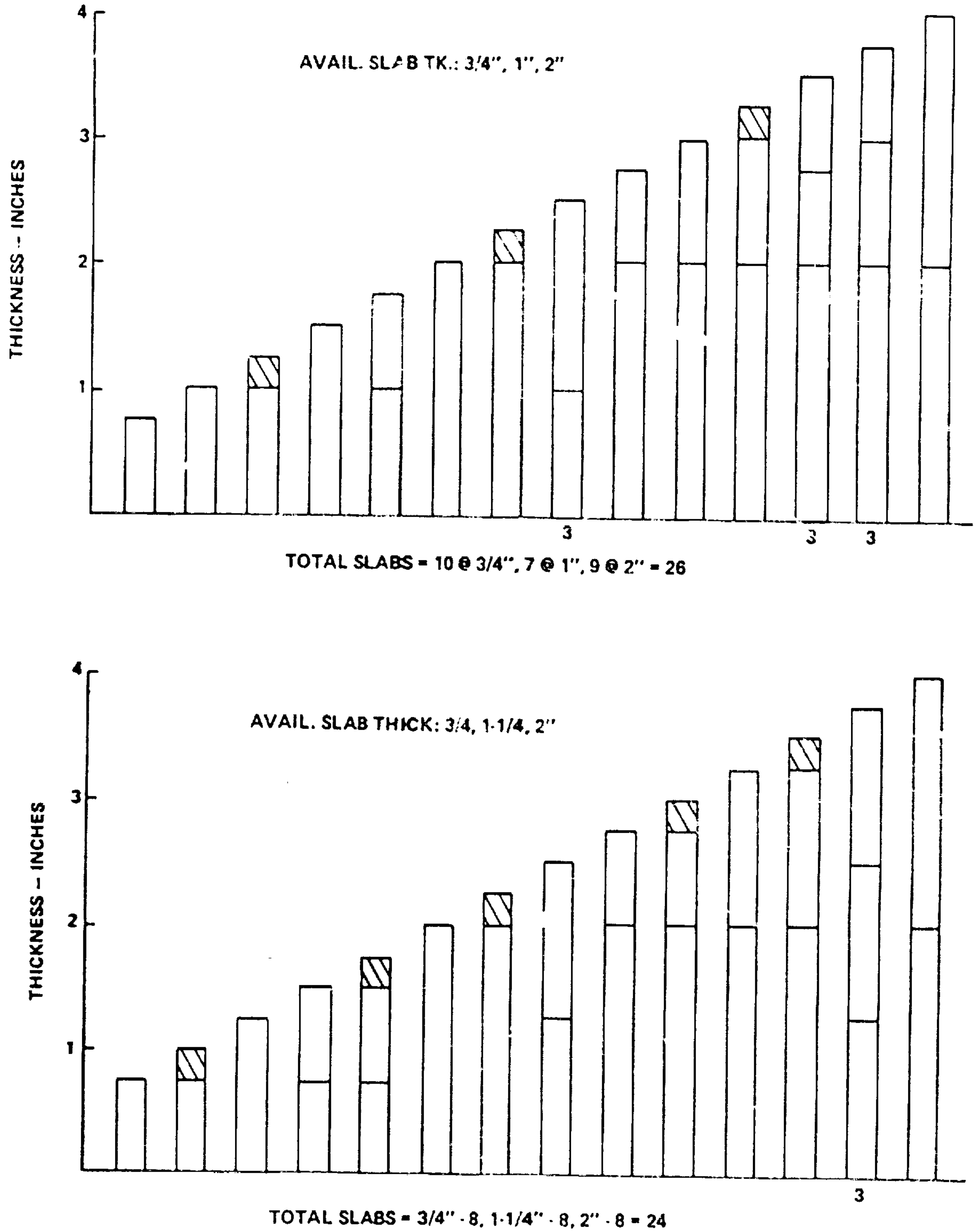

Figure 13. Slab Thickness Comparison

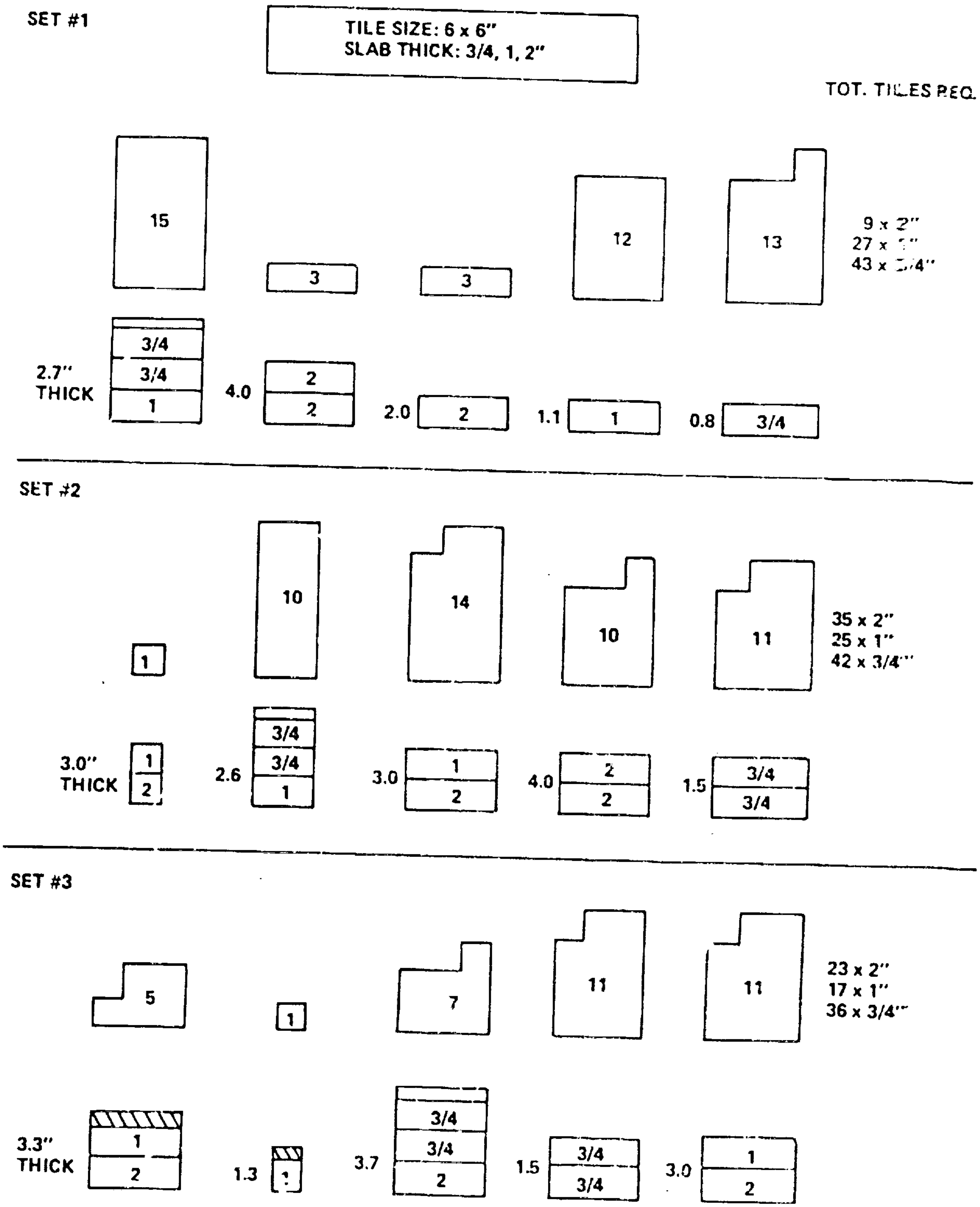

Figure 14. Repair Area Size Distribution

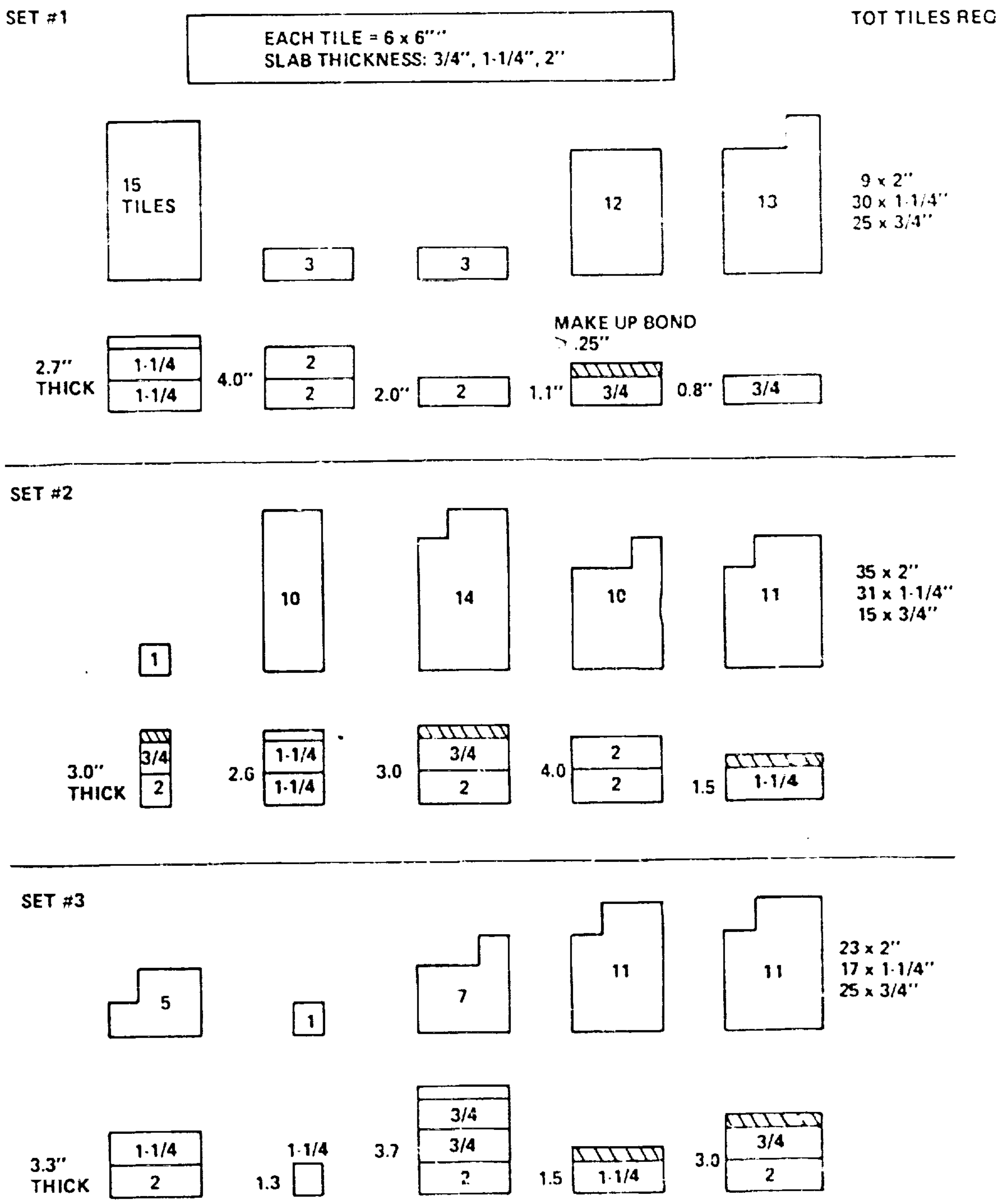

Figure 15. Repair Area Size Distribution

4.3 CURE-IN-PLACE ABLATOR

4.3.1 OBJECTIVES AND APPROACH

The general requirements for the cure-in-place ablator are summarized in Paragraph 4.1. To meet those requirements, the objectives of this task were to: 1) select "off the shelf" materials requiring a minimum of development, 2) select a material or materials offering flexibility in cure time in vacuum, and 3) select an elastomeric material to provide compatibility with the residual of the cured RTV-560 primary adhesive remaining in the cavity.

To provide maximum compatibility of the primary shuttle bond system and the repair system, primary emphasis was placed on silicone rubber compositions based upon GE RTV-560 and the RTV-500 series of materials. These methyl-phenyl based elastomers offer high temperature performance as ablators or as insulators, and, as a result of low glass transition temperature (~ -175°F) will perform successfully at low temperatures as well.

The selected pre-cured ablator (ESM 1004-AP) is based upon RTV-560, and the primary approach of the cure-in-place task has been the investigation of RTV-560 and RTV-577, both unmodified, and modified with fillers as potential repair materials.

4.3.2 CATALYST AND CURE STUDIES

Catalyst Feasibility Study

The specific intent of this sub-task was to rapidly screen and evaluate a wide number of possible catalysts and catalyst combinations not currently used for RTV-560 and RTV-577 and similar silicone rubbers to assess their feasibility for rapid gellation in vacuum. These tests, shown as Table 7, were conducted in laboratory vacuum (10^{6} torr) and at room temperature. This study was limited to a maximum of eight materials in order to rapidly select the most promising material or material/combination for extensive evaluation. Selection of the most promising candidate was on the basis of relative gel times, and degree of cure after 24 hours at room temperature.

In order to conduct these tests as quickly as possible, a laboratory desiccator was fitted with a 1-inch thick flat acrylic cover with pass-throughs for: 1) vacuum hose attachment, 2) pressure gauge, 3) mixer shaft, and 4) hypodermic syringe needle for catalyst introduction.

The general procedure was to place the repair material (RTV-560 for the feasibility study) in a disposable container in the vacuum chamber and de-gas the resin mix. After bubbling had subsided, the catalyst or catalyst mixture was introduced via the syringe and the mixing begun. The pot life (working life, spreadability life, bonding time) and the gel time (time when material is essentially tack-free) were assessed for each combination evaluated. Although not completely applicable, the gel life was determined per the general recommendations of Reference 1, while pot life was considered to be the stall point of the mixer in the vacuum chamber.

The results of the catalyst feasibility tests are listed in Table 8, and the conclusions of the sub-task summarized below.

CONCLUSIONS
CATALYST FEASIBILITY TESTS
(RTV-560)

- Lead, zirconium, zirconium/tin, and zirconium/lead mixtures are not effective.
- Hafnium alkoxy surface skins, and is not recommended.
- Tin complexes, particularly stannous octoate (STO) are recommended. Dilution with silicone fluid is necessary to provide mixing time in stirring type equipment. Dilution may not be necessary for positive displacement flow-through mixing systems.

∴ Explore STO/SF 96-50 mixtures to provide STO concentrations $\geqq 0.3$ WT% of RTV.

Catalyst Concentration and Temperature Evaluation

The most promising candidate catalyst or catalyst combination selected in the previous task were extensively evaluated at several concentration levels over the application temperature range of 40° F to 125° F receiving initial primary attention (current requirements range).

Ref. 1. "Method of Test for Gel Time and Peak Exothermic Temperature of Epoxy Compounds", SPI, Method ERF 2-61.

The evaluations conducted included set or gel time, degree of cure after 18 to 24 hours in vacuum, and hardness versus depth of the material. The planned test matrix is shown as Table 9.

Based upon the screening results, Stannous Octoate catalyst, blended in SF 96-50 silicone fluid was selected as the prime catalyst system candidate.

Five mixtures of catalyst/fluid were evaluated with RTV-560 in the range 0.3 to 1.2 wt. % catalyst based on resin solids (Table 10). Blend No. 2 (0.6 wt. % STO) was selected as the prime candidate to meet the early program objective of gellation to a tack-free state in 15-30 minutes. The room temperature vacuum data is listed in Table 10.

Catalyst blend No. 2 was then utilized to generate hardness and gel times for RTV-560 and RTV-577 at 0°, 40°, and 120°F in addition to the room temperature data previously obtained. That data, Table 11, shows a considerable variation of gel times and show a hardness (after 24 hours) as a function of temperature range. The available data, for RTV-560, and RTV-577 based formulations is summarized in Figure 16 showing time-temperature data. Additional data will have to be accumulated early in the follow-on program to completely define these characteristics for 577E. The data must be accumulated using a static mixer approach.

It should also be noted that prior to inception of this sub-task, the vacuum capability was enhanced by use of an upgraded facility capable of 10^{-4} to 10^{-5} torr with a bell jar large enough to permit catalyst addition and mixing totally within the vacuum environment, that facility is shown as Figure 17. All subsequent materials evaluation testing was conducted in that equipment.

Effect of Vacuum Level

The objective of this task was to demonstrate that the reaction rates of the RTV-560 rubber/catalyst mixtures will not vary as a result of vacuum level and possible related moisture content. A series of experiments were conducted to assess the gel time and cure time of the selected system as a function of vacuum level and time at vacuum. Pre-dried and pre-deaerated base polymer as well as as-received material was included in the evaluations. The evaluation matrix is listed in Table 12.

The vacuum level experiments were conducted using the early desiccator/laboratory vacuum (10* torr) equipment, as well as the 10^{-4} to 10^{-5} equipment, and all tests were conducted at room temperature. In addition, Shore A hardnesses were determined after 8, 16 and 24 hours in the particular environment.

The gellation rates were similar to those shown in Figure 16 for "as received" and for "de-aerated" polymer, whereas polymer heated to 300° F and de-aerated did not cure satisfactorily and/or required 2 to 3 times longer for gellation as a result of loss of entrained moisture as well as air. (Approximately 2 to 2.2 wt.% at 10* torr.) Subsequent tests were conducted with de-aerated material only.

Hardness measurements were made on de-aerated material and compared to data previously generated[2] on an RTV-560 composition using a T-12 (dibutyltin dilaurate) catalyst system. The T-12 system is a slower catalyst system, normally used for bonding applications. As can be seen from Figure 18, cure with the STO (as evidenced by hardness generation) is rapid and provides 24-hour hardnesses similar to 72 to 120 hour hardnesses with the slower system. It is also evident that vacuum level plays little part in rate of cure or final hardness of the system. Data included from the temperature study points out the slower cure rate of the 0° F and 45° F test specimens.

The RTV-500 series of elastomers are condensation type polymers yielding a reaction product as a result of the polymerization reaction. The generalized reaction is:

$$2R_xSiOH \rightarrow R_xSi\text{-}O\text{-}SiR_x + H_2O$$

In actuality, however, the condensation reaction products consist of a mixture of water, ethanol, and low molecular weight poly-siloxanes which are unreacted. The anticipated mass of material released is 2 to 3 wt.% resulting in outgas of these products in vacuum during the polymer cure and formation of a porous elastomeric structure. Figure 19 shows increased void size with increase in vacuum level for materials catalyzed at the same level. (Blend No. 2, 0.6 wt.% STO.) Figures 16 through 19 illustrate RTV-560 (500 poise viscosity) catalyzed, mixed and cured at various vacuum levels. Figure 19A represents a specimen cured in a confined system at one atmosphere.

Figures 19C and 19D show RTV-560 cured at 10^{-4} torr. The specimen shown in Figure 19C was not degassed prior to mix and cure and illustrates the large volume expansion (arrow) to be expected prior to material collapse if non-degassed materials are used. Figure 19D, in comparison, was degassed over-night prior to mixing and cure. The larger void content of Figure 19B represents the difference in amount of entrained gases removed as the resin is more thoroughly degassed. Figure 19B was degassed approximately one hour, while the Figure 19D specimen was treated over-night.

Increased viscosity can also result in a greater amount of trapped condensation products. Figure 19E shows a specimen of filled RTV-560 (RTV-560E) with a viscosity of 1500 poise (three times the viscosity of the base material). This material had been degassed for two hours.

Figures 19F and 19G show porosity of the cured specimens of RTV-577. Figure 19 is of RTV-577 at an initial viscosity of 5000 poise, while the RTV-577E (filled RTV-577) shown in Figure 19G was approximately 14000 poise. Both of these samples were prepared with resin that had been degassed for two hours.

These figures show the importance of thoroughly degassing the resin prior to vacuum cure. For the higher viscosity materials, degassing is more difficult and will require special procedures including either blending under vacuum and/or degassing (with mixing) prior to loading the mixer-applicator.

Regardless of these procedures the vacuum cured materials will have a porous structure of some degree. This structure will be different for the operational static mixer than for laborating batch operations. It will also probably be different for space zero-g with vacuum as compared to one g with vacuum. One sample was taken with the breadboard application discharging into a vacuum of 10^{-5} torr. The 577E material was degassed over night (~ 8 hrs). The cured material resulting from this operation is shown in Figure 20. The porous structure is very similar to that of laboratory RTV-577 (Figure 19F) except for slightly larger pores. This is probably due to less effective degassing. The 577 lower viscosity material was degassed with stirring while the breadboard 577E material of higher viscosity was degassed without mixing due to equipment limitations. The 577 sample (Figure 19F) was considered suitable for repair material performance (concurred by NASA at the mid-term meeting) and the first vacuum specimen from the breadboard dispenser was very similar. It is expected that the slightly larger pore size will be reduced by more effective degassing and will be further reduced by zero-g effects.

Thermal Aging - Reversion Assessment

Reversion is the de-polymerization of a cross-linked polymer under the combined effects of heat and the solvating action of low molecular weight unreacted species. Reversion is a time dependent reaction, generally occurring over a relatively long period of time, and is not regarded as a major problem. However, assessment of the developed cure-in-place ablator was considered important for a man-rated system. Accordingly, specimens of vacuum cured RTV-560 and RTV-577 were aged at 350° F in a closed system for a period of one week. No evidence of softening or de-polymerization was observed, confirming the conclusions reached in References 2 and 3 regarding the advantages of stannous octoate catalyst in promoting reversion resistance.

4.3.3 MATERIAL FORMULATION/PERFORMANCE TRADE OFFS

The basic objective of this task was a limited assessment of potentially desirable benefits of filler additives to the selected cure-in-place ablator material. The fillers were incorporated for several reasons such as lower density, greater char retention during ablation, lower thermal conductivity, and increased polymer viscosity. Candidate fibrous and non-fibrous fillers which were considered are shown in Tables 13 and 14.

Of the potential fibrous and non-fibrous materials several microspheres (Eccospheres SI and PQ Q-Cell 200) and an aluminum silicate fiber (JM 221) were selected for evaluation on the basis availability in the laboratory consistent with temperature capability for the ablative environment. Four formulations were prepared (Table 15) and evaluated via the NASA-JSC Arc Jet Test (Paragraph 4.3.4).

As discussed in Paragraph 4.3.2, it became necessary to dilute the stannous octoate catalyst with a dimethyl silicone fluid SF 96-50 in order to incorporate the catalyst

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Ref. 2. "Cure and Reversion of Silicone Elastomers in Sealed or Confined Systems", Plastics Technology TIS Report 65SD301, C. W. Wilson, 8/9/65.

Ref. 3. "Projected Solution to RTV-560 and PD-162 Material "Reversion" in Closed Systems", PIR 8158-1427, J. Axelson, 11/5/66.

uniformly. In support of the dispenser design activities, a number of viscosity determinations were made to provide design data in the temperature range 40° F to 120° F. Data was obtained for:

1. Stannous octoate (Figure 21)
2. Stannous octoate/SF 96-50 Catalyst Blend No. 2 (Figure 23)
3. RTV-560 (Figure 22)
4. RTV-577 (Figure 23)
5. RTV-560E (Figure 23)
6. RTV-577E (Figure 24)

TABLE 7. CATALYST FEASIBILITY TESTS

Metal Inhibitor	Catalyst Form
Tin	Stannous Octoate Stannous Octoate/SF96-50 Stannous Octoate/RTV-9811
Lead	Octoate or Naphthenate
Zirconium	Octoate or Naphthenate Octoate w/Tin, Lead Promoter
Cerium	Octoate or Hexoate
Hafnium	Alkoxy
Screening Conditions:	
Room Temperature	
Laboratory Vacuum, 10^{*} torr	

TABLE 8. CATALYST FEASIBILITY TESTS (RTV-560)

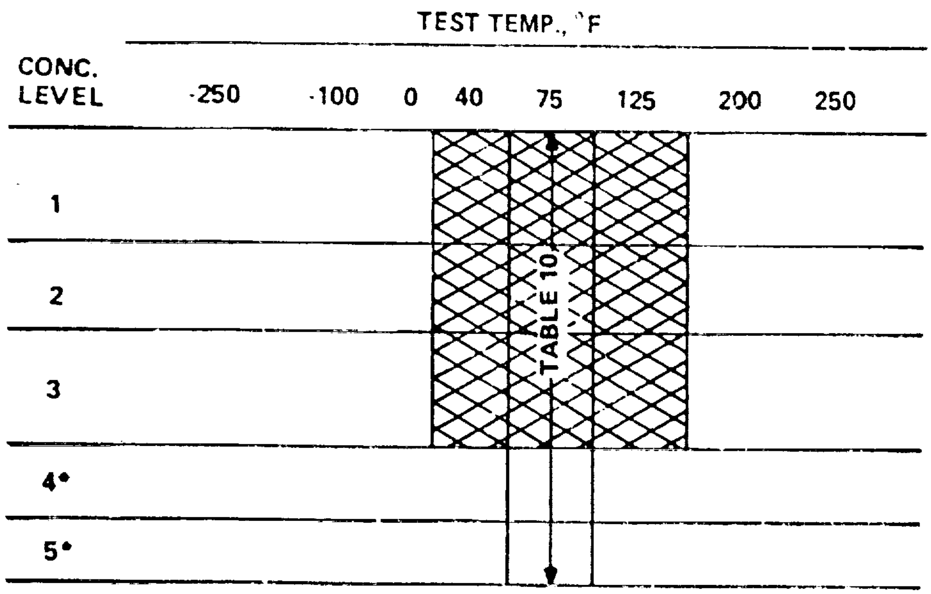
METAL	VAC	MIX TIME	WORKING LIFE	GEL TIME	COMMENTS
• TIN STO*	X	15-20 SEC	30-40 SEC	30-60 MIN	LOCALIZED GEL TOO RAPID. GELS AS BALL AROUND STIRRER BLADES
STO/SF 96-50	X	60-90 SEC	180-200 SEC	30-60 MIN	DILUTION OF STO W/SILICONE FLUID ALLOWS INCREASE IN WORKING TIME AND INCREASES WORKING TIME
RTV-9811	X	SEVERAL MIN	>60 MIN	1-2 DAYS	CATALYST IS MUCH TOO SLOW FOR CURRENT APPLICATION
• LEAD					
OCTOATE		SEVERAL MIN	>4 HR	24 HR	WORKING AND GEL TIME TOO SLOW FOR CURRENT APPLICATION
NAPHTHENATE		SEVERAL MIN	>4 HR	24 HR	
• ZIRCONIUM					
OCTOATE		SEVERAL MIN	>4 HR	SEV DAYS	WORKING AND GEL TIME TOO SLOW FOR CURRENT APPLICATION
+ TIN (STO)		SEVERAL MIN	> 1 HR	SEV DAYS	
+ LEAD (OCTOATE)		SEVERAL MIN	>4 HR	SEV DAYS	
• BARIUM CERIUM MIXED OCTOATE	X	15 SEC	30-40 SEC	30-60 MIN	SIMILAR TO STO W/NO ADVANTAGE OVER TIN COMPOUNDS
• HAFNIUM ALKOXY		5-10 SEC	RAPID SURFACE SKIN	DAYS	SURFACE SKINS OVER VERY RAPIDLY REMAINS SOFT IN CENTER

CONDITIONS. ROOM TEMPERATURE
LABORATORY VACUUM, 10^{0} TORR

*STANNOUS OCTOATE

TABLE 9. PRIME CATALYST EVALUATION

(TEMPERATURE AND CONCENTRATION EFFECTS)



*ADDED

TABLE 10. CATALYST CONCENTRATION TESTS (RTV-560) STO/SF 96-50

NO	STO	SF 96-50	RTV-560	MIX TIME	WORKING LIFE	GEL TIME
1*	0.3	9.1	90.6	> 1 MIN.	5 MIN.	1 - 2 HOURS
2*	0.6	9.0	90.4	1 MIN.	3 MIN.	30-60 MIN.
3*	0.9	9.0	90.1	1 MIN.	3 MIN.	1 HR +
4	1.2	9.0	89.8	30 SEC.	< 1 MIN.	GEL AROUND BLADES
5	0.6	14.2	85.2	1 MIN.	3 - 5 MIN.	1 HR +

CONDITIONS. ROOM TEMPERATURE

LABORATORY VACUUM, 10^0 TORR

*ALSO AT 10^{-4} TORR.

NOTE: #2 BLEND ALSO EFFECTIVE WITH RTV-577 AT NEARLY SAME REACTION RATE

TABLE 11. GEL TIME AND HARDNESS VS. TEMPERATURE

Temp°F	Gel Time	Shore A (at Gel Time)	Shore A (24 hr)
RTV-560, CATALYST BLEND NO. 2			
0	4 Hr.	—	34
45	45 Min.	14	38
70	35 Min.	18	50
120	3 Min.	20	53
RTV-560, CATALYST BLEND NO. 1			
0	8-10 Hr.	—	30
45	2 Hr.	15	35
70	1-1/2 Hr.	17	50
120	5-6 Min.	25	52

NOTE: Hardness variation versus depth was within expected instrument tolerance of ±5 units.

TABLE 12. VACUUM LEVEL EXPERIMENTS

Pressure	Material Condition		
	As-Received	De-aerated	Heated, Deaerated
Ambient	X	X	X
10° TORR	X	X	X
10^{-5} TORR	X	X	X

TABLE 13. LOW DENSITY NON-FIBROUS FILLER MATERIALS

Source	Designation	Particle Size (microns)	Density lb/ft^3	Sp. Gravity gm/cc	Composition	Temp. Limit
Emerson & Cummings	IG 101	10 - 250	14	0.22	Borosilicate Glass	900°F
Emerson & Cummings	FTD 202	10 - 100	10	0.16	High Strength Glass	1800°F
Emerson & Cummings	SI			0.30	Silica	3000°F
Union Carbide (Bakelite)	BJO 0840		7 - 9.6	0.25 - 0.35	Phenolic Resin	
Union Carbide	BJO 0930		6.5	0.21 - 0.25	Phenolic Resin	
Sohio Chemical		65	21	0.34	Glass Sodium Borosilicate	1400°F
Kureha	Krecaspheres	50 - 200			Carbon	6600°F
PQ	Q-CEL 200	75	11	0.18	Silicate	

TABLE 14. COMPARISON OF FIBROUS REINFORCEMENT

Fiber	Specific Gravity	Fiber Length, In.	Fiber Diameter, Microns	Tensile Strength, 10^2 psi	Modulus of Elasticity, 10^6 psi	Heat Resistance °F	Coef. of Thermal Expansion, 10^{-6}/in°C	Thermal Conductivity, cal/cm^2/sec/°C-cm	Ratio of Modulus of Elasticity to Density 10^9 in 70°F	Ratio of Modulus of Elasticity to Density 10^9 in 2000°F	Estimated Price Range $/lb
Synthetic - Inorganic											
1. Conventional glass (E)	2.6	...	5-15	250-300	10.5-12	600 1500	2.8	.003	1.4	...	.32-2.00
2. Beryllium glass	2.6	...	5-15	280	12-20	1500	6	.003	2.1	...	65-75
3. Quartz (fused silica)	2.2	...	8-10	100-350	10-25	3500	5-8	.002	2.9	1.7	50-75
6. Aluminum silicate	2.7-3.9	up to 10	2-20	100-600	2-15	3300	1-8	...	1.06	.7	...
7. Aluminum Oxide (Al_2O_3)	3.93	...	250	100	55	2600	7	.08	3.85	3.1	2.00
8. Beryllium Oxide (BeO)	3.0	up to 4	100	3.0	40-50	4650	5.8	.65	4.2	2.5	...
9. TitaniumOxide (TiO_2)	4.2-4.4	up to 4	100	...	20-50	2700 3450	7-9	.15	...	...	...
10. Zirconium Oxide (Z_1O_2)	5.5	up to 4	100	...	26	4880	...	...	1.3	.6	...
10a. Magnesium Oxide (MgO)	3.65	...	100	70-150	25-32	5070	...	.0015	2.4	1.0	...
11. Rock Wool	2.8	up to 4	1-22	...	...	2800	2-6	.0001	...	...	.05-.20

TABLE 15. FILLED RTV FORMULATIONS

Formulation	Material	Vendor	Designation	Wt %	Density, pcf
D	Silicone Rubber	GE	RTV-560	85.0	45.2
	Microspheres	Emerson & Cummings	SI	15.0	
RTV-577E	Silicone Rubber	GE	RTV-577	91.2	69.2
	Fibers	JM	221	4.8	
	Microspheres	Emerson & Cummings	SI	4.0	
RTV-560E	Silicone Rubber	GE	RTV-560	91.2	71.8
	Fibers	JM	221	4.8	
	Microspheres	Emerson & Cummings	SI	4.0	
F	Silicone Rubber	GE	RTV-560	90.0	51.9
	Spheres	PQ	Q-Cell 200	10.0	

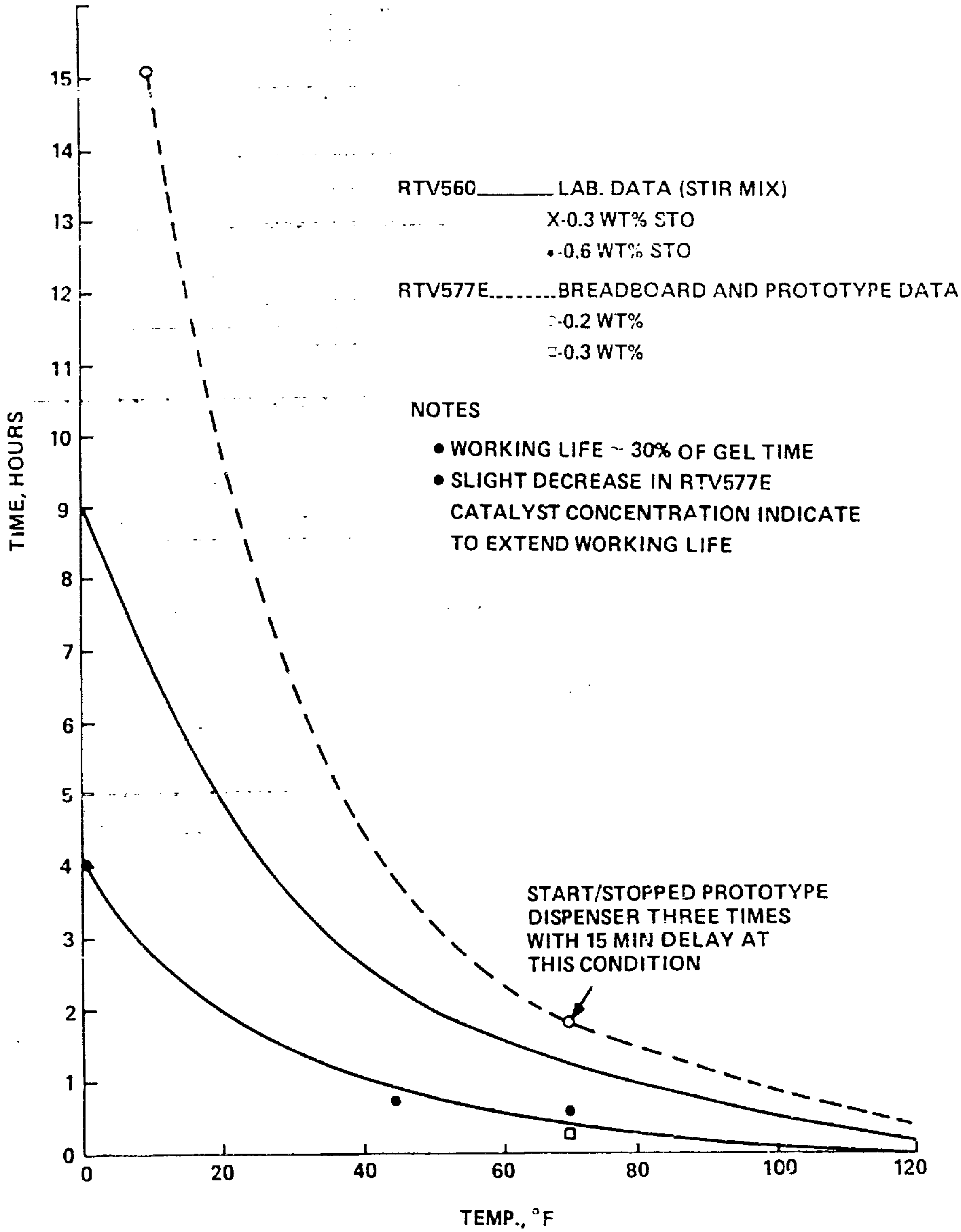


Figure 16. RTV-560 and RTV-577E Gel Times vs Temperature

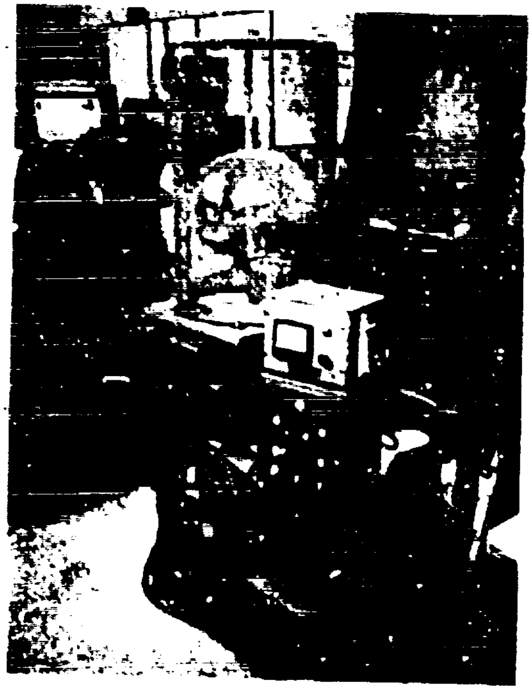


Figure 17. Vacuum Facility, 10^{-4} to 10^{-5} Torr

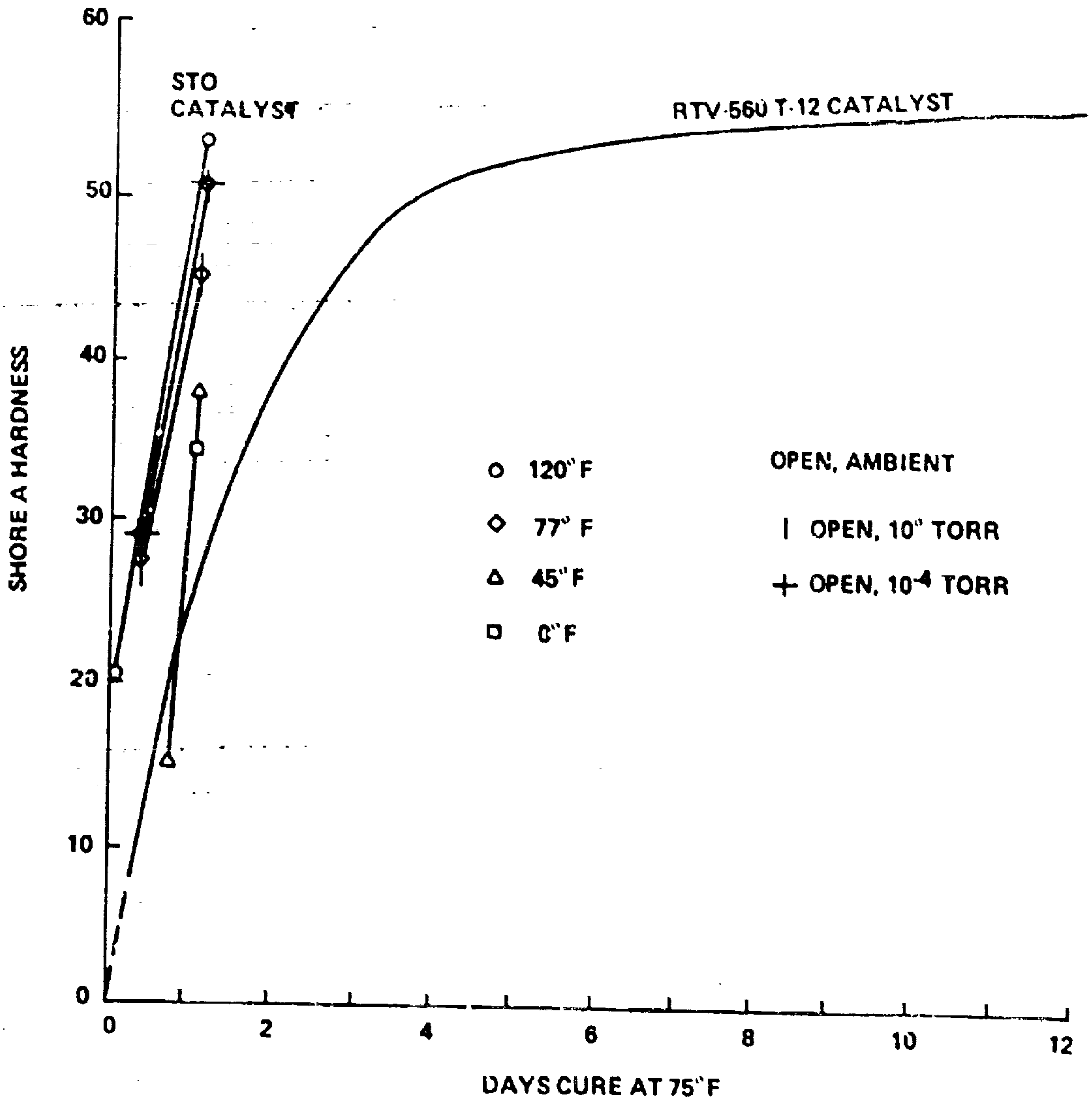
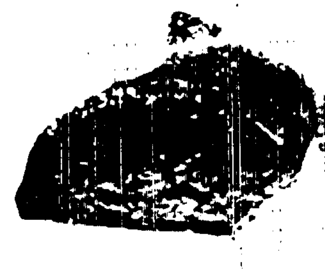


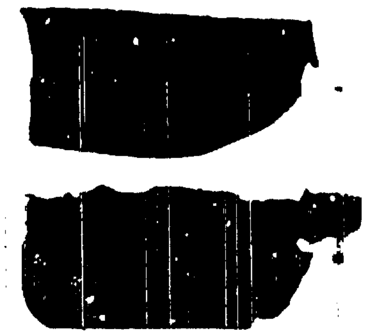
Figure 18. RTV-560 Hardness with Vacuum Effects

A. RTV-560, 0.6 WT % STO
1 ATMOSPHERE, CONFINED
SYSTEM

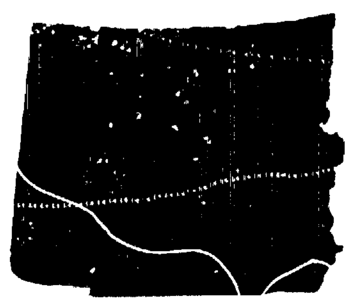
B. RTV-560, 0.6 WT % STO 10^{-2} TORR, RESIN
DEGASSED ~ 1 HOUR



C. RTV-560, 0.6 WT % STO 10^{-4}
TORR, RESIN NOT DEGASSED

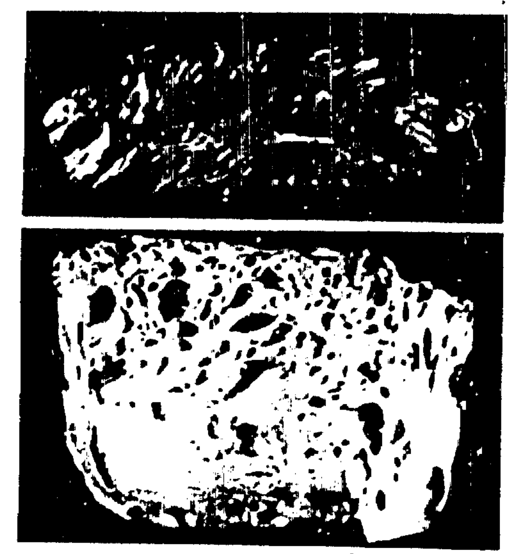


D. RTV-560, 0.6 WT % STO 10^{-4}
TORR, RESIN DEGASSED
OVERNIGHT



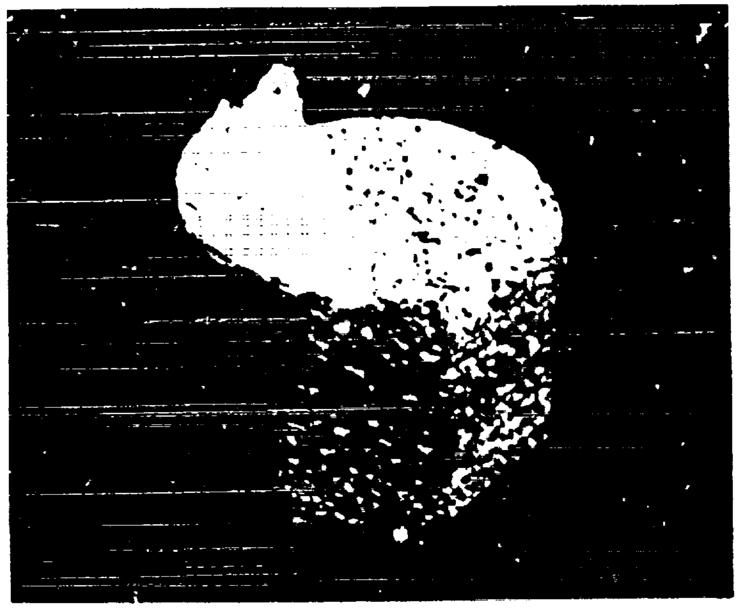
E. RTV-560, 0.6 WT % STO 10^{-4} TORR
2 HOUR DEGASS AT 10^{-4} TORR

F. RTV-577, 0.6 WT % STO 10^{-4} TORR
2 HOUR DEGASS AT 10^{-4} TORR



G. RTV-577E, 0.6 WT % STO 10^{-4} TORR
2 HOUR DEGASS AT 10^{-4} TORR

Figure 19. Cured Material Porous Structure Comparisons



• DEGASSED IN 28 HOURS WITH MIXING
• 10^{-5} TORR

Figure 20. Vacuum Cured Specimen from the Breadboard Dispenser

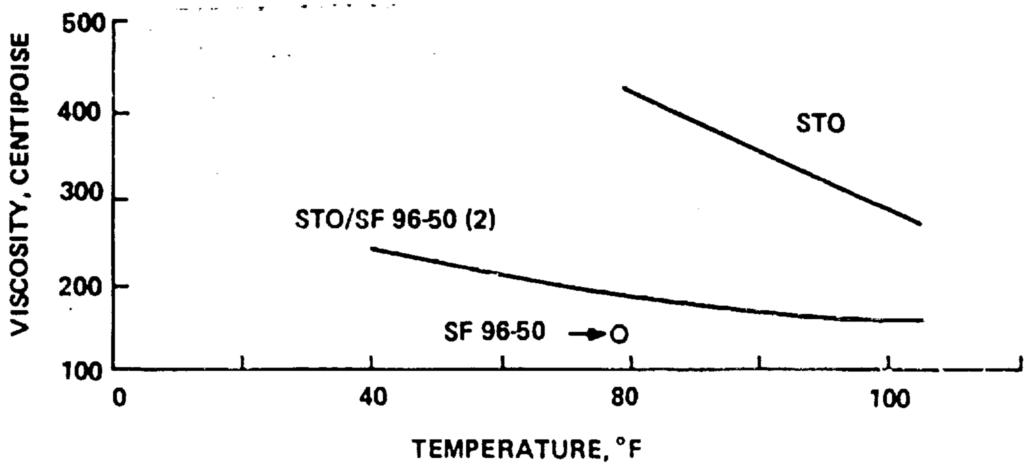


Figure 21. Viscosity Versus Temperature Catalyst and Catalyst Mixture

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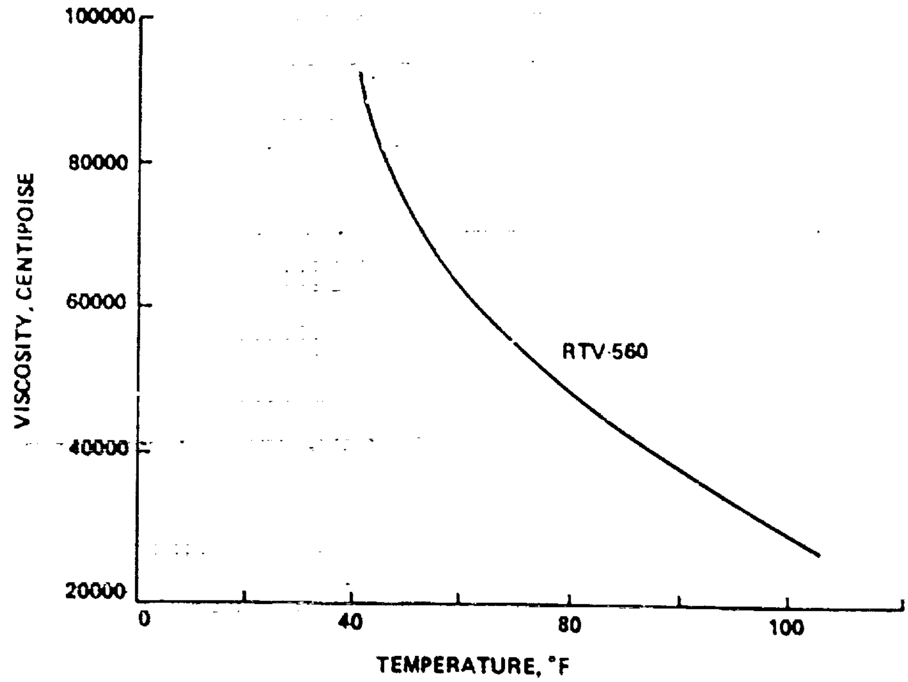


Figure 22. Viscosity vs. Temperature RTV-560

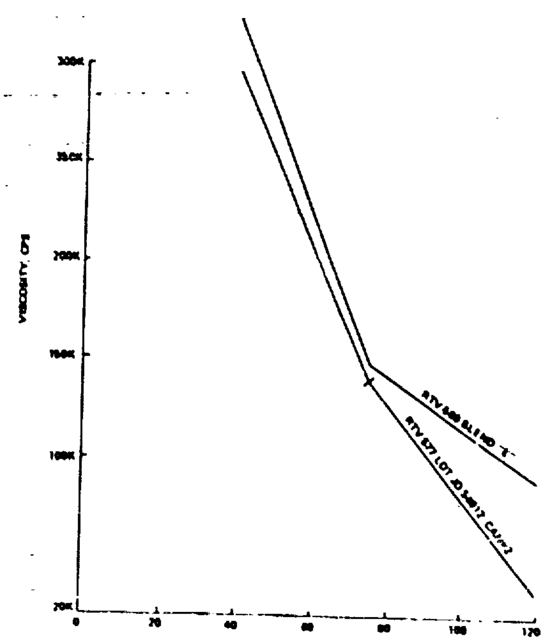


Figure 23. Viscosity vs. Temperature RTV-577 and RTV-560E

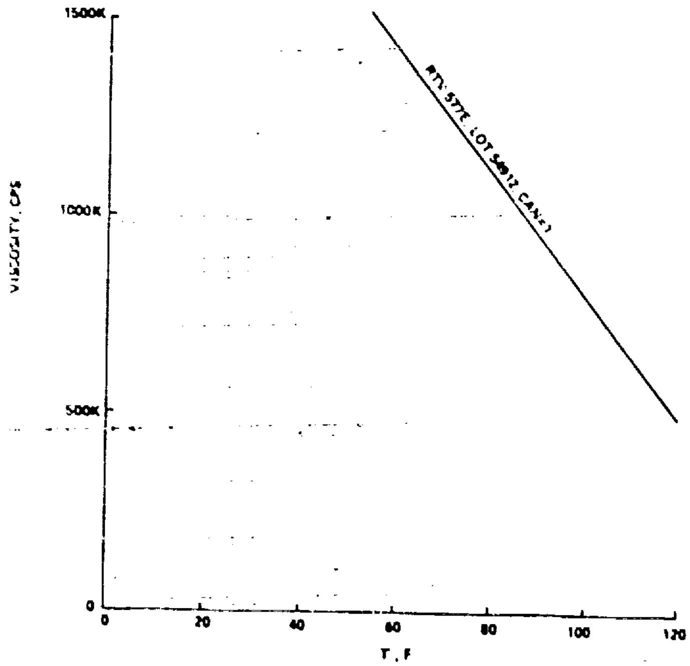


Figure 24. Viscosity vs. Temperature RTV-577E

4.3.4 ABLATION TESTS

Text Matrix and Objectives

The Arc Jet Ablation Tests, conducted by NASA-JSC had several objectives:

a. Evaluate base-line RTV-560 and ESM 1004AP in the shuttle environment

b. Assess ablation performance of RTV-577 versus RTV-560

c. Provide assessment of several filler classes and types for formulation guidance.

The first series of test specimens were 3.875-inch discs of HRSI 2.0 inches thick with 2.0 inch diameter holes to contain the repair material. The test model configuration was as shown in Figure 25. All materials were cast in place at ambient pressure. Chromel-alumel thermocouples (20 gauge) were installed at nominal 1/4, 1/2 and 1.0 inch depths from the front face. The specimens prepared and tested are shown in Table 16. The formulations of samples "B" and "C" are GE Company proprietary, while the remainder of the formulations may be found in Table 15. Table 16 also provides objectives and expected results for each model.

A second series of specimens, two in number, was also prepared at ambient pressure for test. The test specimens were 6 x 6 x 2-inch HRSI tiles with 3.0-inch diameter holes to contain the test material. In addition to thermocouples in the repair material at the same depths, as before, two additional TC's were provided, one in the HRSI at 1/4 inch depth and one for the HRSI backface. The two additional specimens were:

		Nominal PCF
1.	RTV-560E	71.8
2.	RTV-577E	69.2

NASA personnel provided X-rays and actual in-depth T/C locations, and pre- and post-test photographs for each model. In addition, a Nomex felt insulator (SIP) and an aluminum structure were bonded to each model as shown in Figure 25 and two additional thermocouples, one at the surface of the SIP and another at the structure surface, were installed at JSC.

Test Environment and Results

All samples were tested for a 600 second time period for the arc environment described below, which simulates a high heating rate area on the shuttle vehicle. The test environments were as follows:

$\dot{q}_{cold\ wall}$ - 42 Btu/ft^2 sec

H_R - 6600 Btu/lb

P_e - 0.18 psia

The samples designated A1 and A2 in the pre-test photograph (Figure 26) are both unfilled RTV-560 (ρ_V - 59 lbs/ft^3). Both samples performed as expected, exhibiting excessive swelling as seen in the post test photographs in Figures 26B/26 C/D and allowing no significant thermal penetration (BFΔT - 8° @ 600 seconds), at the SIP backface, Figure 27. Sample A1 which expanded more severely than any of the other models had a mushroom shaped char at completion of the test. This char layer was attached to the model at the completion of the test, however, during the removal process (from the sting) it was unavoidably jarred loose. Referring to the post test photographs it is apparent that although sample A2 also experienced considerable expansion (0.371"), it did not exhibit a deformed char layer. During the test the sting arm holding sample A1 was observed to undergo a number of severe forward and aft vibrations, which most probably resulted in loss of the periphery char and caused the surface deformity. This malfunction was traced to a loose electrical connection, controlling the left arm movement, which was corrected for subsequent tests.

From the photographs of the sectioned models, it is evident that at some point during the expansion process, both samples developed an air-gap between the charred layer and the residual virgin material. The char layer was most probably retained as a result of the lateral expansion that appears to have occurred; however, no fractures are evident in the RSI holder.

The surface and in-depth temperature history responses of these two models are quite similar as shown by comparing Figures 27A and 27B. Both sets of data indicate little or no temperature rise at the structure surface. Analytical predictions were not generated for comparison to these data because the material has only been characterized in the low temperature regime, and char conductivity specific heats, and thermogravometric data are not available. A comparison of available RTV-560 material data, to comparable ESM1004AP data (Figure 28), shows that the thermal characteristics in the virgin state are similar. However, this does not necessarily mean the materials will perform in a like manner. Char characteristics of the two materials will determine their respective in-depth temperature responses. In fact, a comparison of the ESM1004AP post-test models (Figure 29B and 29C) and test data (Figures 30A and 30B) to previously presented RTV-560 data shows that the temperature responses through the first inch of the materials are quite different. If the materials had performed in a similar fashion (comparable char expansion, char depth, etc.) the observed differences could possibly have been attributed to unique char formation, however, referring to the photographs of the sectioned models (Figures 26 C1/2 and 30B) the difference in expansion are evident, along with the development of a large air-gap in both RTV samples. Comparing the data defined on Figures 27 and 30 shows that the thermocouples in the ESM models responded much more rapidly than those in the RTV samples, although no appreciable temperature rise was measured at the structure of either material. This comparison suggests that expansion and/or development of the air-gap in the RTV samples began almost immediately. If expansion began at the onset of the test, the effective location of the thermocouples from the surface of the RTV samples would be greater than that of the corresponding T/C's in the ESM models, both of which experienced less than 120 mils expansion (Figure 29). If an air-gap did exist in the RTV-560 early in the test, then the primary mode of heat transfer was radiation heating which would also produce lower than expected temperatures. Thus, the differences in the measured in-depth response between the RTV and ESM models is probably a combination of both effects.

Analytical predictions have been generated through the use of one-dimensional Heat Condition code (REKAP-Reference 4) and the analytical model outlined in Reference 5. These results are compared to the ESM measured data on Figure 30. These predictions are based on a cold wall heat flux of 42 Btu/ft^2 sec with an enthalpy level of 6600 btu/lb. It can be seen that the analytical model is underpredicting the temperature response for comparable T/C locations up to 1.0" from the surface. In addition, the model is also underpredicting the surface temperature measurement obtained by pyrometry. These measurements have been adjusted to account for a surface emissivity of 0.85 which is the value employed in the analysis. Noting the difference between the measured and predicted

Ref. 4. Hannon, J.D. "User's Manual for the One Dimensional Heat Condition Program" (REKAP), 10-18-65.

Ref. 5. Florence, D., "Thermodynamics Ground and Flight Test Performance of a Low Density Elastomeric Silicone Formulation", 10-23-67, Data Memo TTC-110.

surface response and having data which indicates ESM undergoes on exothermic reaction at certain environment levels, the quoted enthalpy and predicted gas injection coefficent (B'g) were compared to a correlation (Reference 5) based on theory and data, in order to determine the test environment regime. This comparison is presented on Figure 31, which indicates any combination of B'g and enthalpy that lie below the zero gas injection line would be in the exothermic regime. The plotted data point from this test does lie below the boundary indicating a heating rate of about 10% greater than that employed in the analysis. Also, during the tests it was noted that the thermocouples located at the structure surface indicated a higher temperature response than the sensors located at the surface of the SIP. Since the models were encompassed in a water-cooled holder there was no possibility that the structure temperature was being driven by an outside energy source. Its response was due entirely to conduction. Therefore, the unexpected response of the structure T/C's prior to the response of the SIP sensor leads one to conclude that there may be two-dimensional conduction effects. A comparison of the thermal differsivity versus temperature for the RSI and ESM is shown on Figure 28, which supports the theory that two dimensional conduction is occurring. Thus, it's believed that the combined effects of exothermicity, two-dimensional conduction, and expansion, which is not accounted for in the predictions, are primary causes for the measured versus predicted temperature differences.

Samples C1 and C2 (Figure 32) are ESM Part A samples (unfoamed ESM). The post-test photographs indicate that both models expanded more severely (0.333" and 0.283", respectively) than the standard ESM models, and that the ESM Part A experienced some surface melting which was not observed on any of the other models. As was noted in the sectional A1 and A2 models, the photographs of the sectioned C1 and C2 models also show the development of an air-gap between the charred and residual virgin material. The air-gap is much more apparent in the sectioned C2 model although it is not as large as that observed in test samples A1 and A2. In model C1 the air-gap is smaller and appears to be in the development stage relative to the C2 model. The temperature performance of the two models are presented on Figures 33A and 33B, which show that with the exception of the nominal 0.25-inch depth sensor, late in the test, the models performed consistently. At above 450 seconds into the test the shallow T/C on the C2 model began to rise at a more rapid rate than the corresponding sensor on the C1 sample. This difference could be the result of the 50 mil expansion difference between the two models, which as pointed out in the discussion of the RTV-560 models effectively positions the sensors at different in-depth locations from the surface. Also, another factor that may be producing these temperature differences is the 0.25-inch T/C in the C1 model appears to be located where the air gap is developing, whereas in the C2 model the air-gap is well below the first sensor. In general, the overall performance of these samples is considered not as good as the standard ESM performance and only comparable to that of the RTV-560. The material will limit backface temperature response, however the expansion, foaming/melting, and char retention may be a problem.

The fourth material that was tested was Model D, a modified RTV-560 (filled with ceramic microballoons - Figure 34). Post test photographs of this sample show that the model expanded excessively (~0.284"), developed an air-gap, and the RSI holder cracked to a depth of about 1.0 inch. The temperature performance of this sample is described on Figure 34D. It should be pointed out that this sample was not at an equilibrium temperature level at the initiation of the test. This was the result of an automatic test shut-down, at 110 seconds into the test, due to a vacuum loss in the test chamber. Restart did not occur for approximately 4 minutes and the initial temperatures shown on this figure are those measured at this time. The thermocouple, nominally placed 0.50-inch from the surface, failed about 100 seconds after the test restart and responded in a very erratic manner; therefore, no reliable temperature data is available for this location. The SIP and structure measurements indicate no appreciable temperature rise at these locations and the overall response of this sample appears to be consistent with the other RTV models. In comparison to the ESM model the backface performance is basically the same; however, the in-depth response, up to 1.0-inch, is consistently lower than the ESM which is most probably due to the differences in expansion and/or the development of the air-gaps.

Sample E which is RTV-577 with ceramic microballons and inorganic fibers (Figure 35) was tested with the previous sample in the right sting arm. RTV-577 is basically RTV-560 without the iron-oxide. Post-test photographs show that this model experienced very little expansion (0.052") and that the apparent char depth is considerably less than that of any of the other models. As can be seen from the top view photograph some cracking of the surface char layer and foaming did occur. In addition, it appears that some local melting occurred at the interface of the RSI holder and the RTV-577 samples. Despite this, the low expansion, char retention and relatively small char depth of this material, along with its temperature performance, which is similar to that of the ESM, indicates this material is a primary candidate for the cure-in-place repair material.

The final model tested was RTV-560 with inorganic spheres (Figure 36). Measurements indicate this model expanded about 0.20-inch and as can be seen in the photographs some cracking of the surface char and slight foaming did occur. The char depth of this model is considerably larger than that of the RTV-577 model. It has approximately the same char depth (0.75") that is evident on the ESM samples. However, unlike the ESM samples, a crack between the char and remaining virgin material is apparent from the sectioned view of this model. The models temperature performance is described on Figure 36D, and comparison of this data to the measurements from the other samples shows that the shallower T/C's responded more like the ESM, rather than the other modified RTV-560 models.

Conclusions and Recommendations

The backface temperature response data of all models showed that any of the tested samples would adequately limit the structure temperature rise. However, based on the expansion characteristics, char depth, char retention, and the materials ability to resist fracturing, two of the materials, ESM-1004AP (Samples B1 and B2) and RTV-577 (Sample E), outperformed the other candidates for this environment. RTV-577E was selected for the cure-in-place ablator on the basis of this performance data.

A summary chart which briefly defines the test results (temperature rise, weight loss, and expansion) is presented in Table 17.

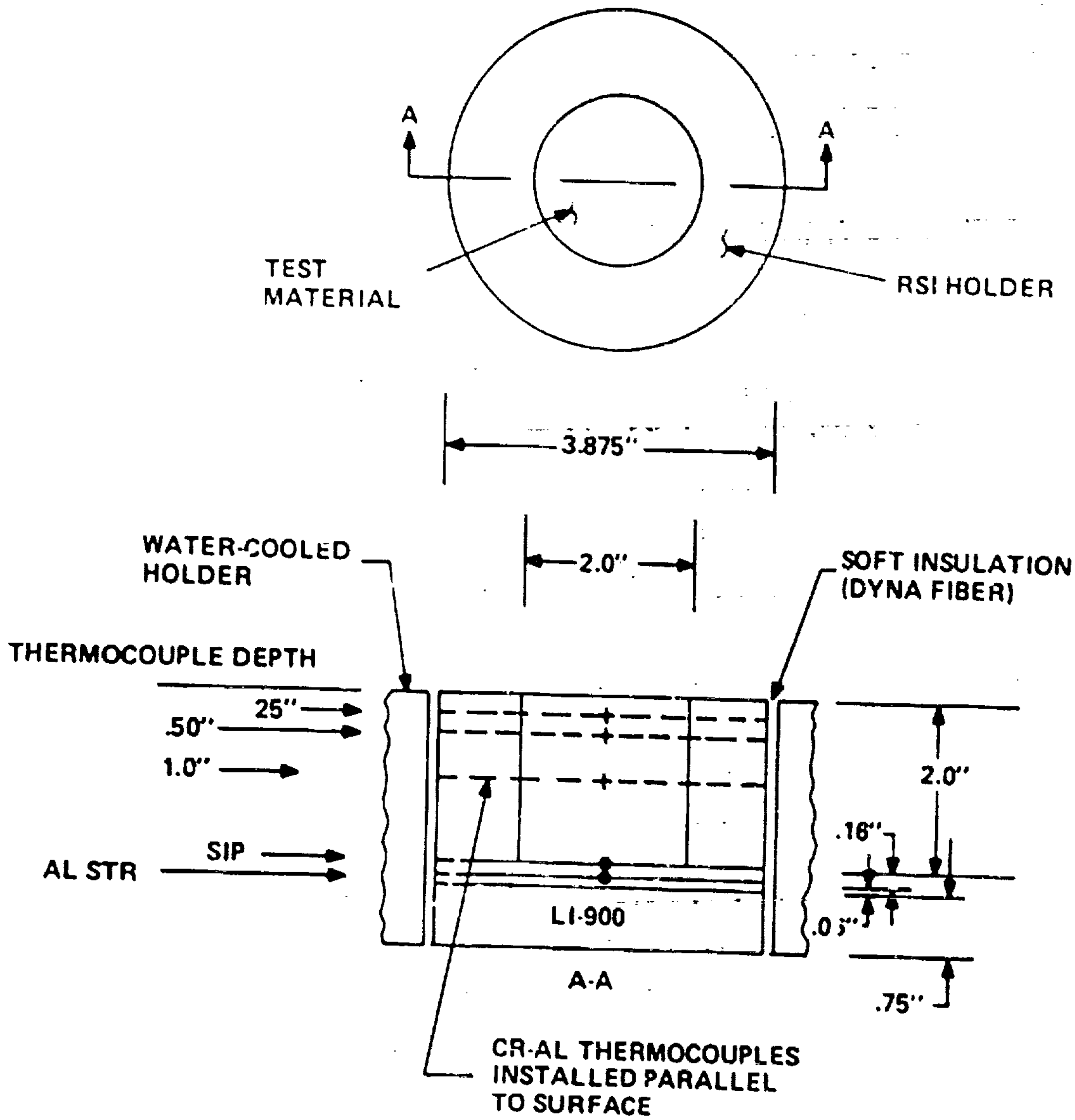
Subsequent testing (channel flow) at NASA-JSC is scheduled for larger samples to determine the performance repeatability of the material (RTV-577E and a similarly filled RTV-560E model), under a high shear environment channel flow configuration.

TABLE 16. ABLATION TESTS - SERIES #1 (EOS 5 MW ARC HEATER)

SAMPLE DESIGNATION	NO. SPECIMENS	DENSITY PCF	MATERIAL	OBJECTIVE	COMMENTS
A	2	88.6	RTV-560	BASELINE CURE-IN-PLACE	MAY SWELL EXCESSIVELY
B	2	35.	ESM 1004AP (LOT WS 918A1)	BASELINE PRE-CURED ABLATOR	PROVEN MATERIAL FOR REPEAT DATA AND REFERENCE COMPARISON
C	2	90.7	ESM "PART A"	EFFECT OF CURRENT ESM REINFORCEMENT IN SOLID RTV 560	POTENTIAL BETTER CHAR RETENTION AND/OR SWELL CONTAINMENT
D	1	45.2	RTV-560 W/CERAMIC MICROBALLOONS	REDUCE DENSITY AND PROVIDE POROSITY	POTENTIAL SWELL CONTAINMENT REDUCE THERMAL CONDUCTIVITY REDUCED KIT WEIGHT
E	1	69.2	RTV-577 W/CERAMIC MICROBALLOONS AND INORGANIC FIBERS	SAME AS ABOVE PLUS POTENTIAL REDUCED FOAMING DURING CURE AS A RESULT OF HIGHER VISCOSITY	SAME AS ABOVE
F	1	51.9	RTV-560 W/INORGANIC SPHERES	REDUCE DENSITY AND PROVIDE POROSITY LOWER MELT TEMP. FILLER THAN "D"	SAME AS ABOVE PLUS ASSESSMENT OF FILLER MELT RANGE

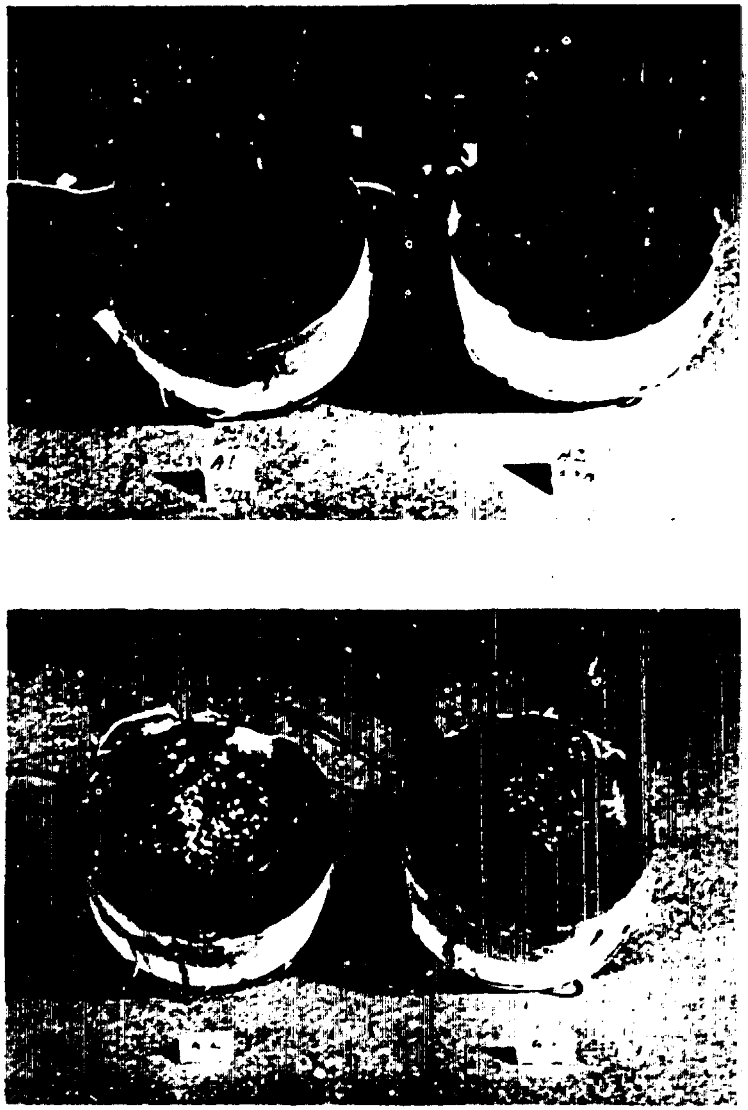
TABLE 17. SHUTTLE TILE REPAIR KIT TEST RESULTS

Material	Sample	Expansion at Model	Wt. Loss (grams)	Test Results
RTV-560	A1 A2	0.5007" 0.371"	18.8 11.3	Both samples exhibited excessive swelling, as expected. Sample A1 had a mushroom shaped char at comple[illegible] of test, however loss of sub-layer char ma[illegible] ve been a result of sting arm vibrations. B[illegible] face (SIP) T/C showed no significant therm[illegible] penetration ($\Delta T \sim 8.0°$ @ 600 sec).
ESM-1004AP	B1 B2	0.117" 0.110"	6.3 6.9	Both samples exhibited slight swelling and retained char layer. Minimal cracking of char in near surface layer observed. RSI holder (32) appears to have experienced some melt at ESM/RSI interface. Test shutdown (due to oxygen loss) occurred 424 sec into testing of sample B1 (SIP T/C indicated ~3° temperature rise). Time lapse greater than 5 minutes (soak) resulted in SIP temperature rise ~ 27° prior to sample insertion for completion of 600 [illegible] test period. Final temperature rise abou[illegible]. Sample B2 was tested for 600 sec (continuously) -- measured temperature rise was 8°. Comparison of the first 400 seconds for each sample indicates similar performance.
ESM (Part A)	C1 C2	0.3327" 0.2832"	8.5 9.3 A1	Expansion for both samples was less severe than samples A1 & A2. Char was retained; however, both models appear to have experienced some melt and had cracks in the char layer. SIP temperature rise, (C1)~7.1° - C2 (~3.1°).
RTV-560 W/Ceramic Microballoons	D	0.2837"	7.5	Test shut-down occurred 110 seconds into test. Approximately 4 minutes passed prior to restart. Thermocouples responded erratically. Sample expanded somewhat less than pure RTV models. RSI holder cracked to a depth of about 1.0".
RTV-577 W/Ceramic Microballoons	E	0.052"	12.4	Experienced less expansion but cracked more than other models. Also, re-solidified foam was apparent on test sample and RSI holder. SIP temperature rise ~ 9°.
RTV-560 W/Quartz Spheres	F	0.2031"	7.8	Sample experienced some cracking in char layer and slight foaming. Expansion was less than that observed for samples A1 & A2. SIP temperature rise ~ 10°.

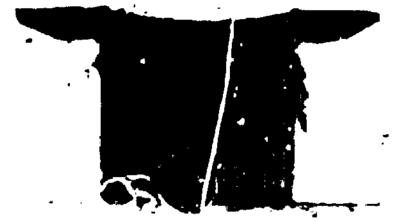


NOTE: SIP- NOMEX FELT

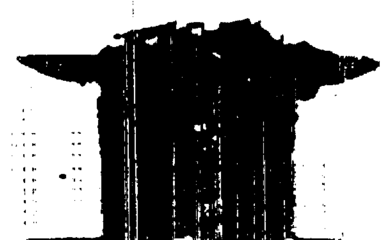
Figure 25. Test Model Definition



B. POST TEST



SAMPLE A1 RTV-560



SAMPLE A2 RTV 560

C. POST TEST (SECTIONED)

Figure 26. Model A1 and A2 Photographs

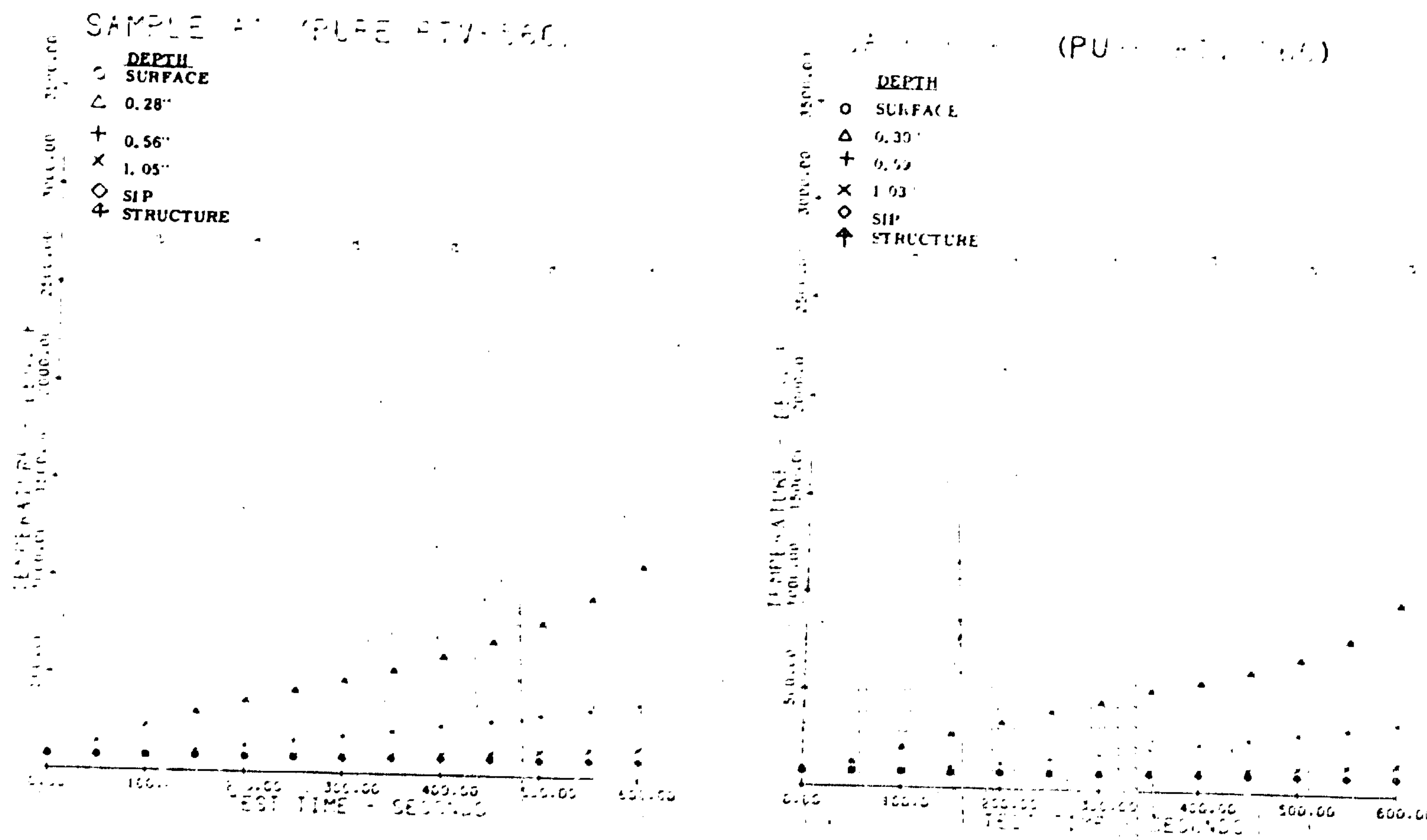


Figure 27. Model A1 and A2 Thermocouple Data

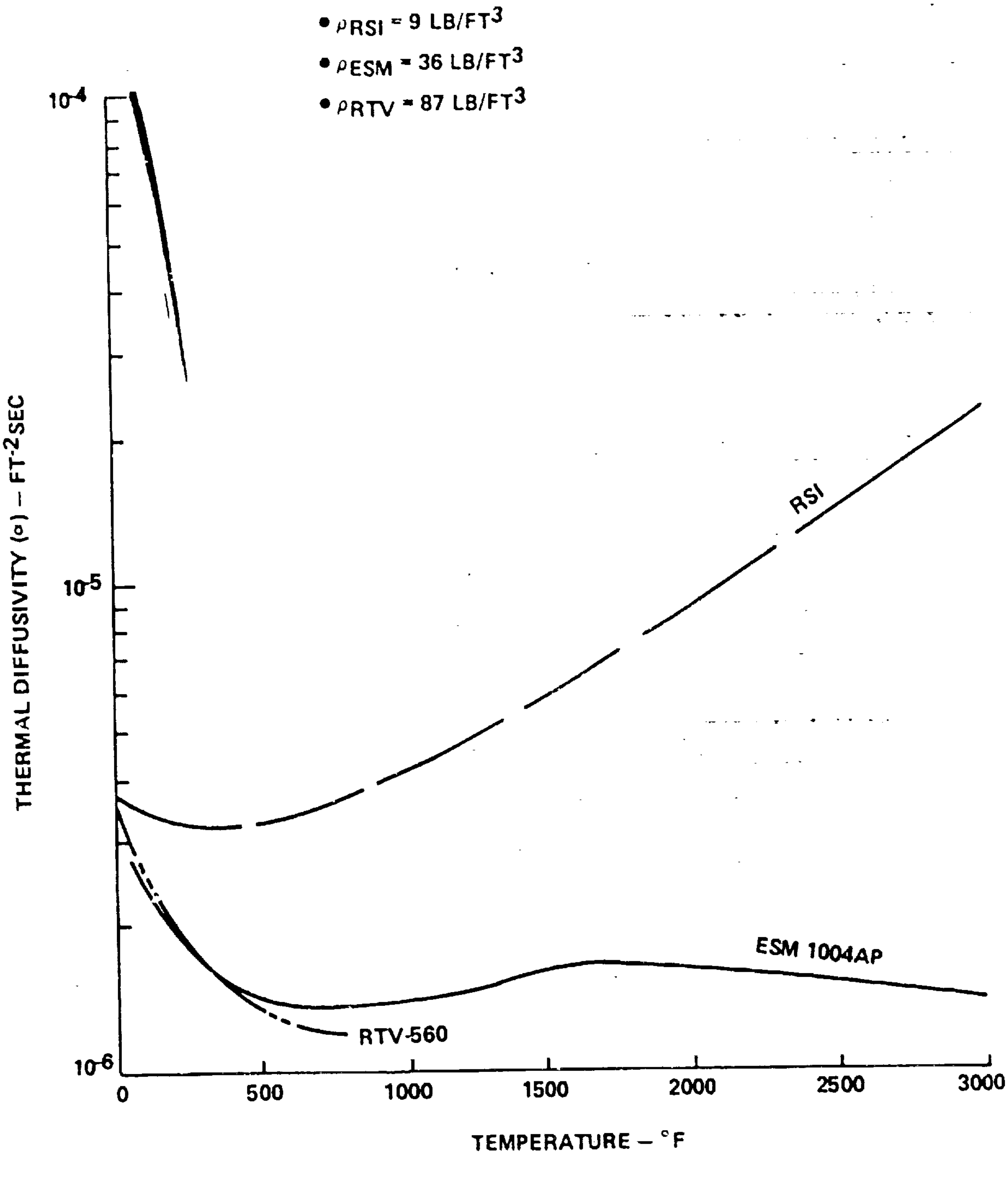
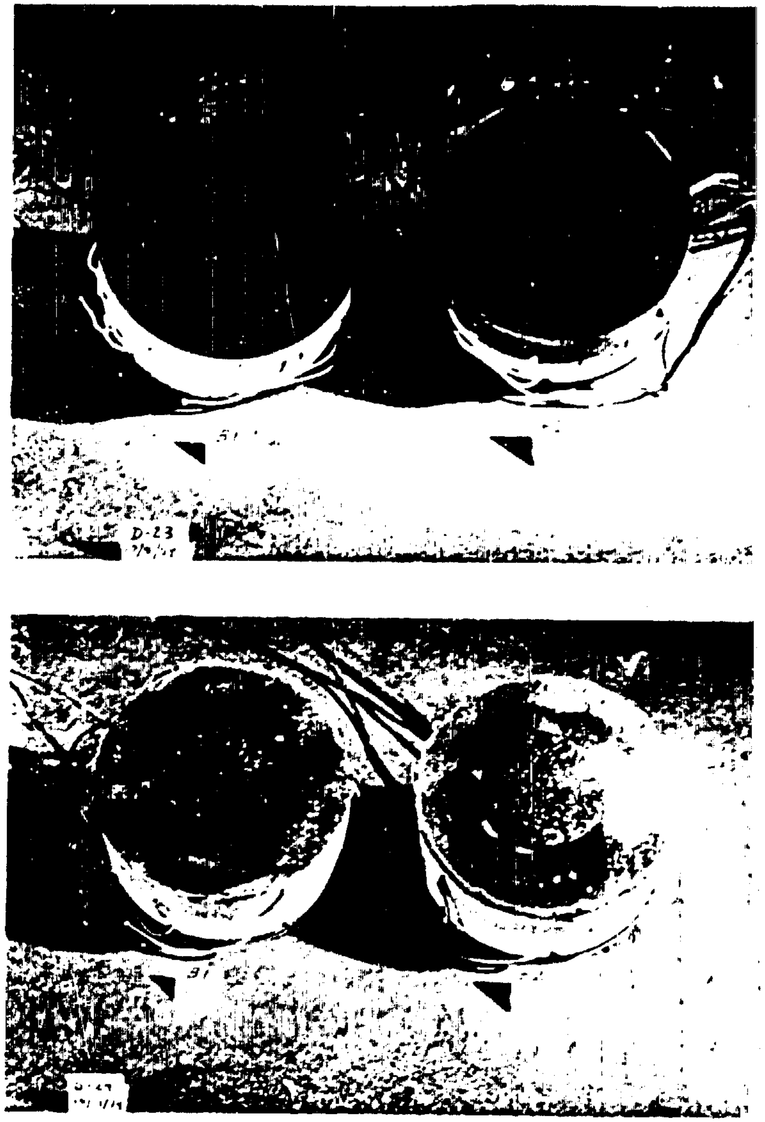
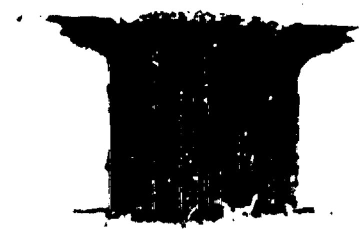


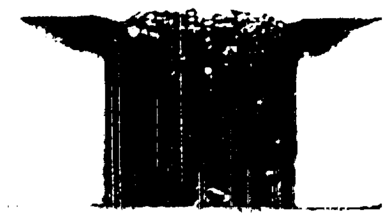
Figure 28. Thermal Diffusivity Comparison



B. POST TEST



SAMPLE B1 ESM-1004AP



SAMPLE B2 ESM 1004AP

C. POST TEST (SECTIONED)

Figure 29. Model B1 and B2 Photographs

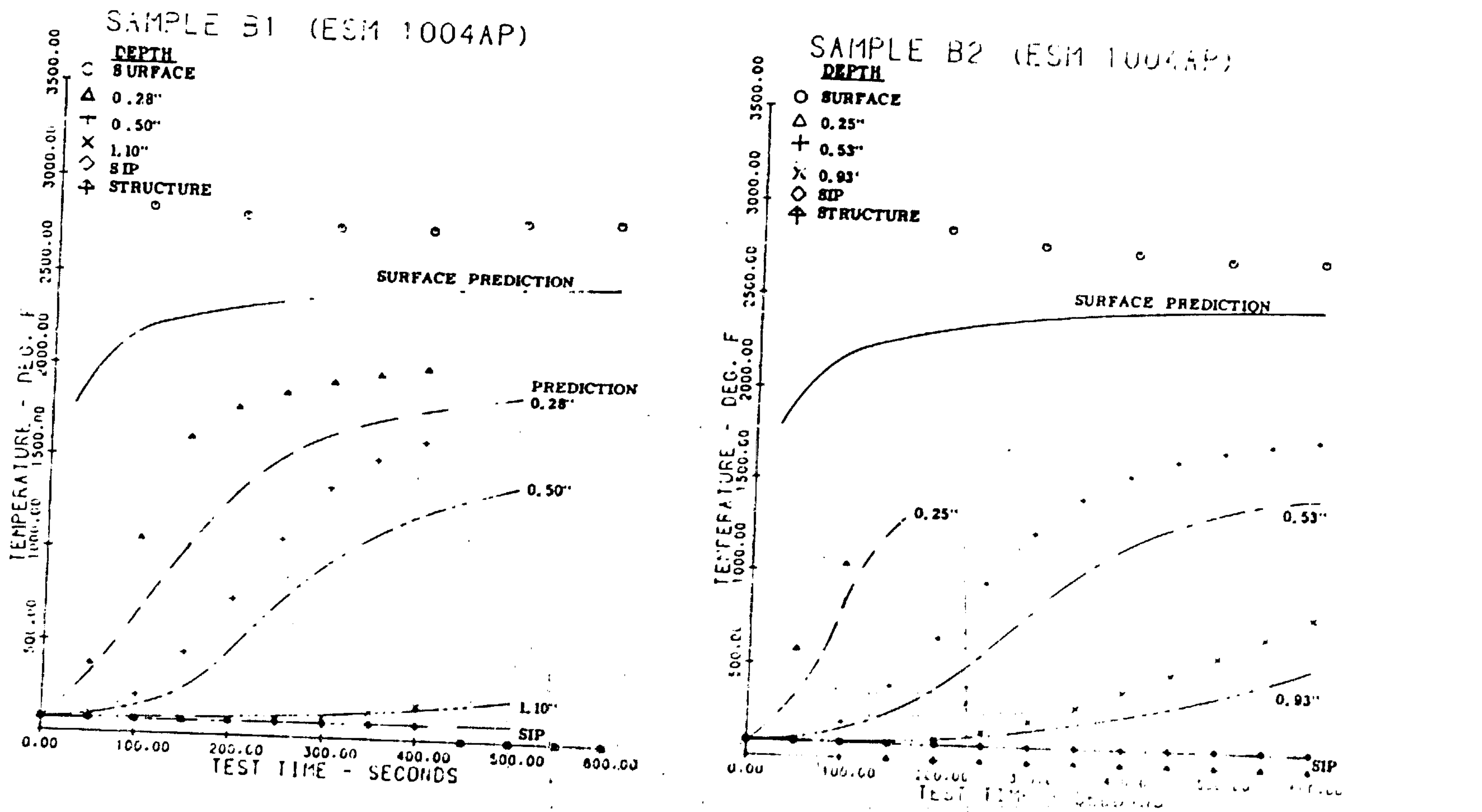


Figure 30. Model B1 and B2 Thermocouple Data

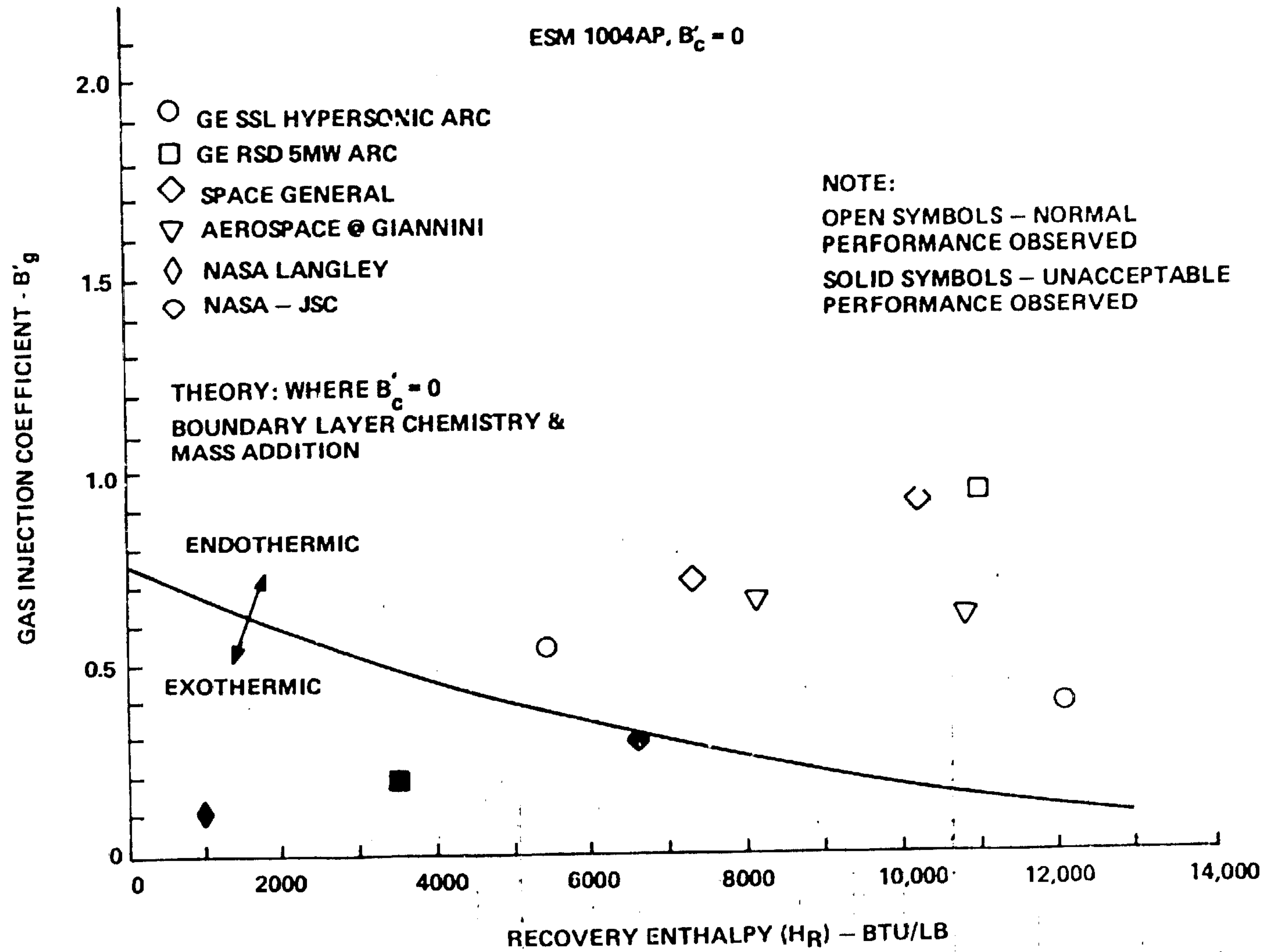
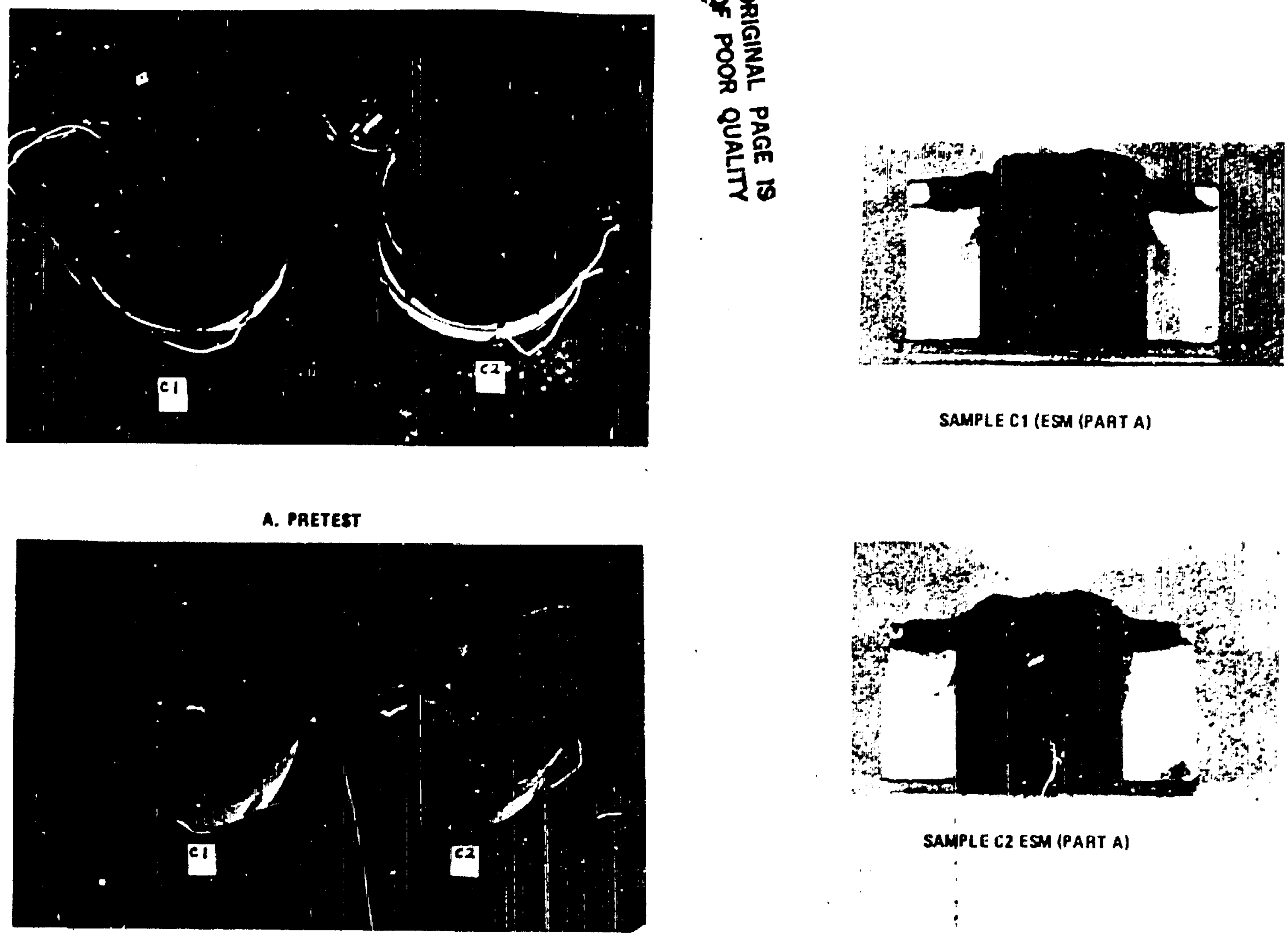


Figure 31. ESM Performance Regimes



A. PRETEST

B. POST TEST

SAMPLE C1 (ESM (PART A)

SAMPLE C2 ESM (PART A)

C. POST TEST (SECTIONED)

Figure 32. Models C1 and C2 Photographs

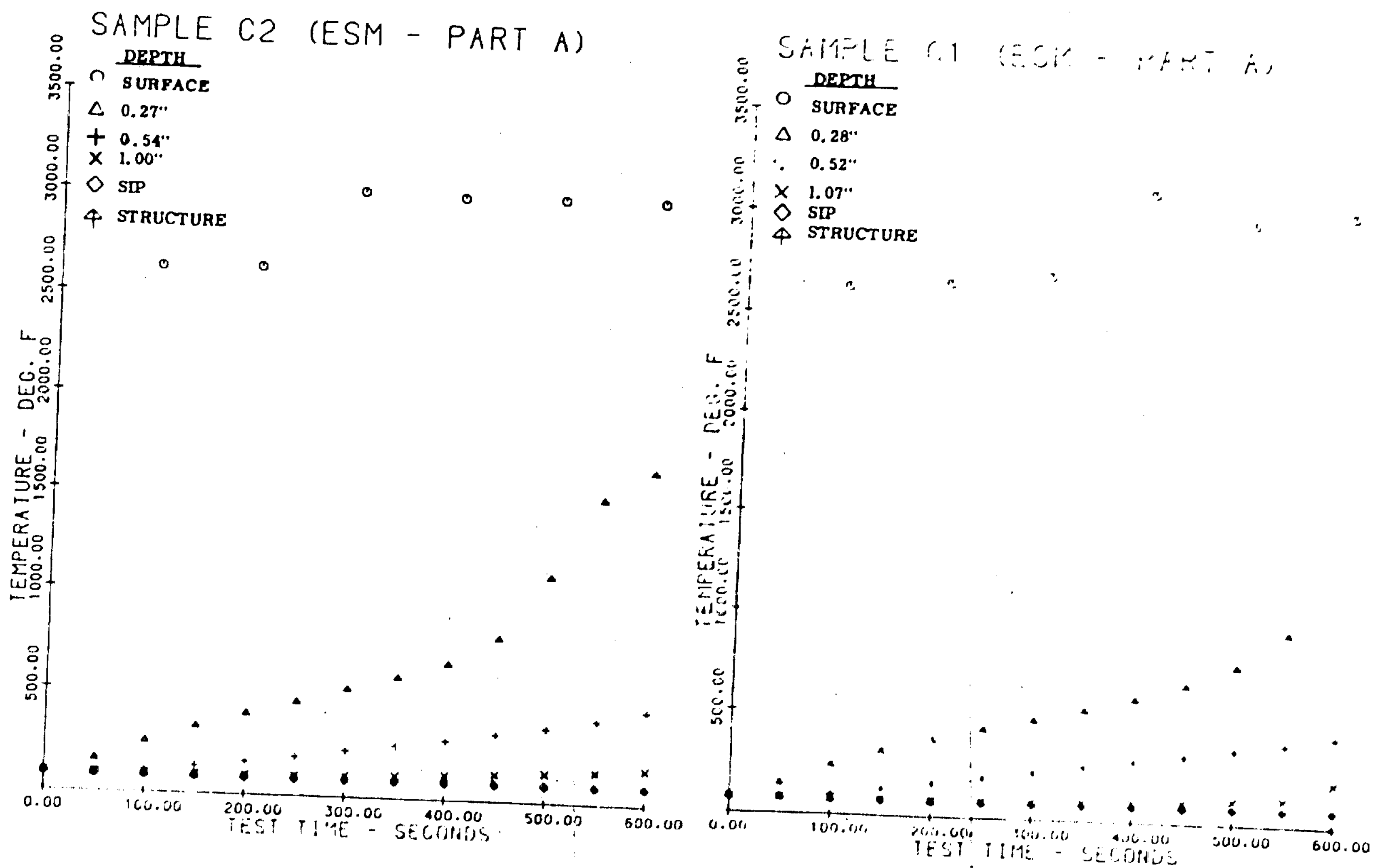
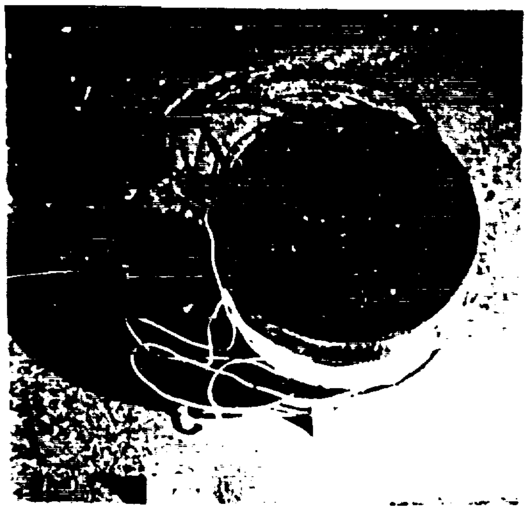
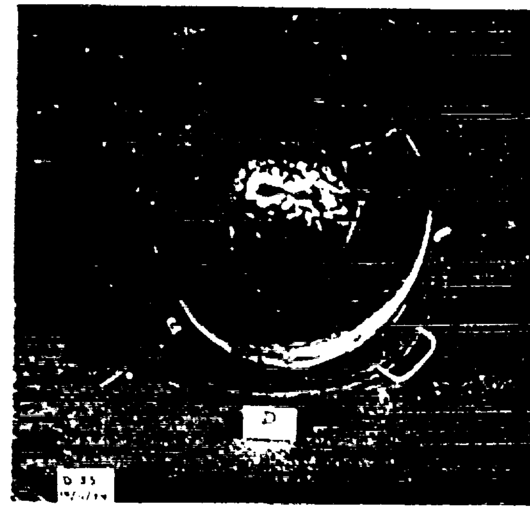


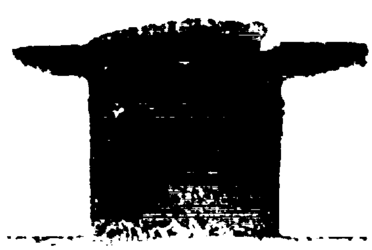
Figure 33. Model C1 and C2 Thermocouple Data



A. PRETEST

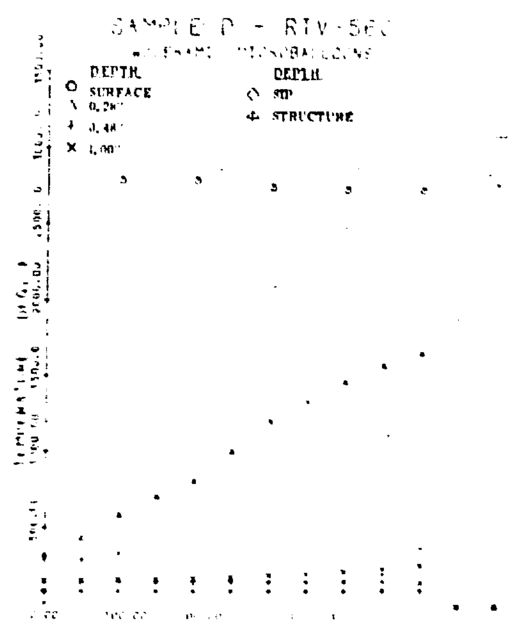


B. POST TEST



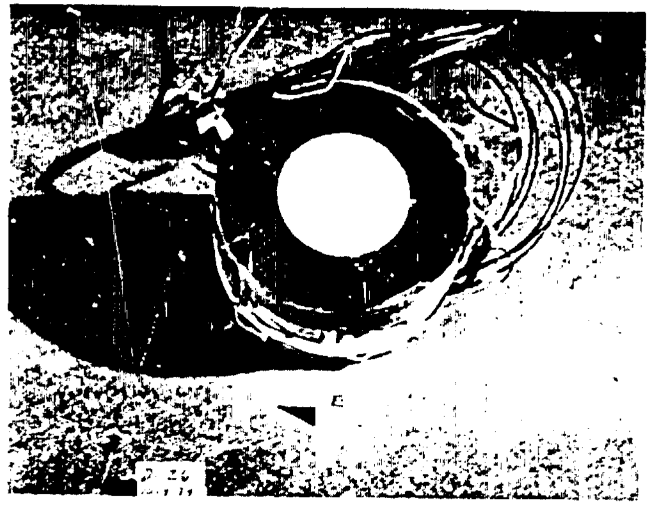
SAMPLE D RTV-560 W/CERAMIC MICROBALLOONS

C. POST TEST (SECTIONED)

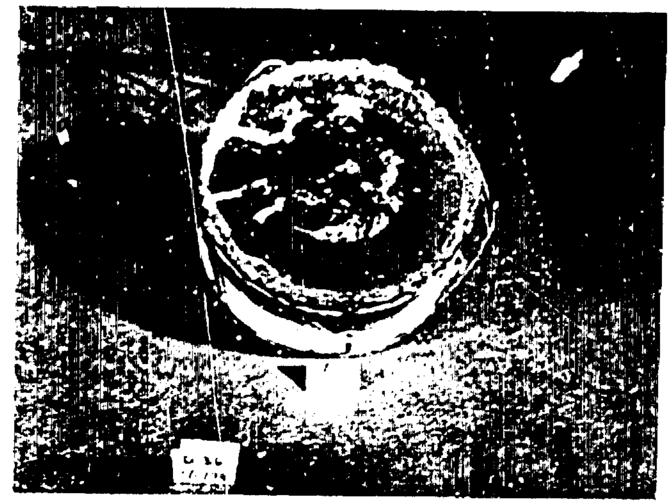


D. THERMOCOUPLE DATA

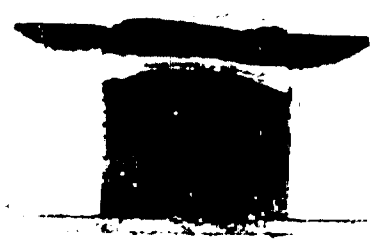
Figure 34. Model D Photographs and Thermocouple Data



PRETEST

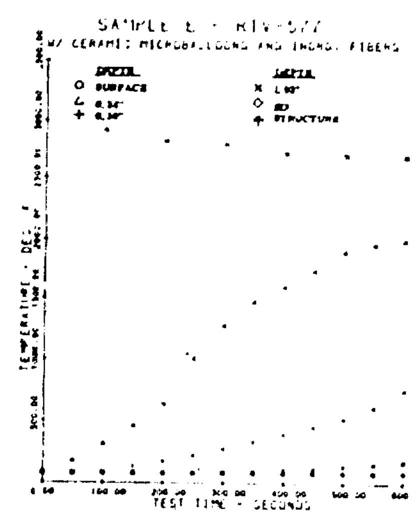


POST TEST



SAMPLE E RTV-577 W/CERAMIC MICROBALLOONS

POST TEST (SECTIONED)



THERMOCOUPLE DATA

Figure 35. Model E Photographs and Thermocouple Data

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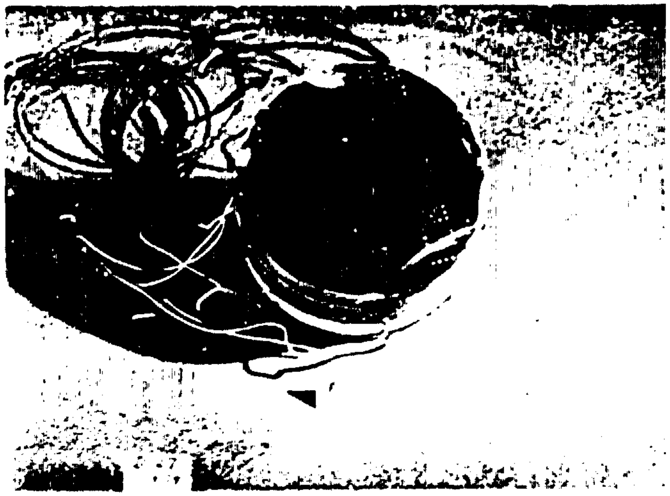
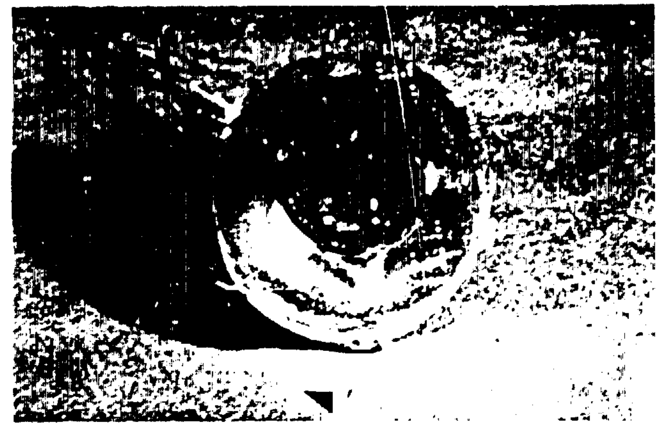
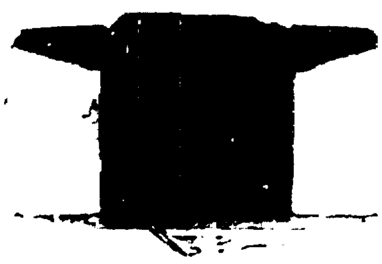
OF POOR QUALITY



A. PRETEST

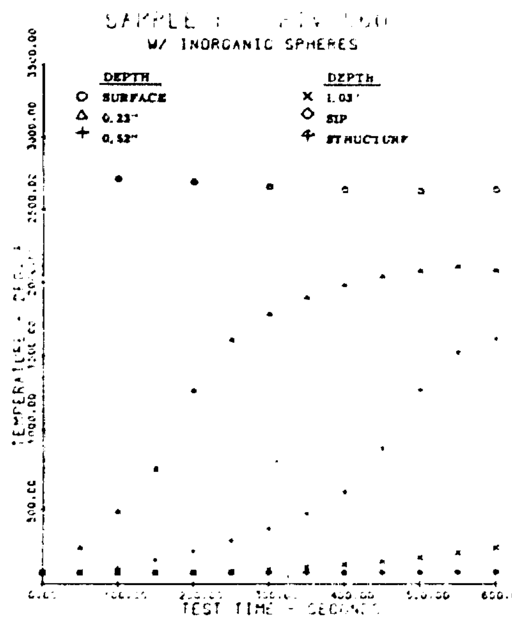


B. POST TEST



SAMPLE F RTV-560 W/QUARTZ SPHERES

C. POST TEST (SECTIONED)



D. THERMOCOUPLE DATA

Figure 36. Model F Photographs and Thermocouple Data

Figure 37.

Reserved for late ablation tests; data not available.

4.3.5 PROPERTY EVALUATIONS

Pre-Cured Ablator Bond Test

The objective of this task was to determine bond capability of the selected ablator-cured-in-place bond interface.

A series of flatwise (butt) tensile strength tests were conducted using the selected ablator and the cure-in-place bond materials to determine the bond strengths of the ablator cure-in-place ablator at elevated temperature. This test matrix is shown as Table 18, and the specimen configuration as Figure 38.

The test data for RTV-560E and RTV-577E bonded to ESM 1004 AP is listed in Tables 19 and 20 and plotted on Figures 39 and 40. The failure modes were primarily adhesive to the ESM 1004 AP at room temperature with loads in excess of the 40 psi requirement. Post-test photos are shown as Figure 41.

Cure-in-Place Ablator Bond Tests

The objective of this task was to investigate bond strengths of the cure-in-place ablator and associated substrates.

The mechanical properties determined were bond strength (butt tensile) to substrate conditions identified by NASA-JSC. The test matrix is shown in Table 21.

The test data for RTV-560E and RTV-577E bonded to GFE RTV-560/SIP is listed in Tables 22 and 23, and is plotted in Figures 39 and 40. The failure modes for both repair materials were mixed: adhesive to the RTV-560 coated SIP and cohesive in the SIP. In almost all cases of adhesive failure, post-test observations indicated ripping of the SIP as well, undoubtedly leading to the low level failure stress. Additional specimens were then fabricated of RTV-560E bonded to a well-cured RTV-560 surface only. Tests at 150°F resulted in an average failure load of 99 psi (Table 24). This data point is plotted on Figure 39 for comparison and indicates that SIP strength is the limiting factor. Post-test photos of the SIP tests are shown as Figure 42.

Test data for RTV-560E and RTV-577E bonded to GFE HRSI tile is listed in Tables 25 and 26, and plotted in Figures 39 and 40. The failure mode for RTV-560E was 100% cohesive in the tile near the bond interface with the exception of specimen no. 14 at 40°F where failure also occurred in the center of the tile specimen. The failure mode for RTV-577E specimens was primarily cohesive in the tile; however, as a result of higher viscosity and poorer wetting several of the specimens also exhibited adhesive failure to the tile. The post-test photographs are shown as Figure 43.

The specimen configurations in all cases were identical to that shown in Figure 38, with the RTV-560 SIP or the tile in place of the ESM. The specimen flow plan is shown in Figure 44.

4.3.6 SELECTED MATERIAL AND ALTERNATES

A family of repair materials based upon RTV-577 and RTV-560 have been identified to meet the following requirements:

a. A cure-in-place ablator has been developed to maintain the structure below 350 F during entry.

b. The material may be easily applied via caulking gun approaches.

c. Gellation in the 15 to 30 minute range in vacuum as initially specified.

d. Cures of 24 hours provide 40 psi strength or greater.

e. The cure-in-place may be used as the pre-cured ablator adhesive.

The selected cure-in-place material is RTV-577E, a fiber, microsphere filled RTV-577. The material has successfully met the ablation test requirements, exceeds 40 psi flatwise tensile strength to the pre-cured ablator and to RTV-560, and provides sufficient viscosity to prevent flow into the remaining tile joints. While the viscosity of RTV-577E is very high, flow in the mixer-applicator does not indicate this to be a problem.

Investigation of RTV-577/RTV-511 blends (with fillers) should be pursued to provide viscosity control or optimization if required for mixer-applicator effectiveness.

TABLE 18. FLATWISE TENSILE TESTS

Test Temp F*	Number of Specimens	Comments
40	5**	
	5	
150	5	Assess Failure Mode as well as Ultimate Strength
	5	
350	5	
	5	

*15 minute soak at temperature prior to test
** 5 EA RTV-560E & RTV-577E

TABLE 19. BUTT TENSILE TESTS RTV560E TO ESM 1004-AP

Specimen No.	Temp. (°F)	Strength (psi)	Failure Mode: Adhesive 560E to 1004-AP	Failure Mode: Cohesive 1004-AP at Interface
1	40	83.7	100	0
2	"	92.8	100	0
3	"	116.0	80	20
4	"	103.0	30	70
5	"	101.5	75	25
		$\bar{X}$ 99.4 SD 12.1		
6	150	54.8	100	0
7	"	52.2	100	0
8	"	46.5	100	0
9	"	60.0	99	1
10	"	57.3	100	0
		$\bar{X}$ 54.2 SD 5.2		
11	350	35.8	100	0
12	"	19.5	99	1
13	"	31.3	100	0
14	"	27.4	100	0
15	"	15.0	100	0
		$\bar{X}$ 25.8 SD 8.5		

TABLE 20. BUTT TENSILE TESTS RTV-577E BONDED TO ESM-1004-AP

Specimen No.	Temp. (°F)	Strength (psi)	Failure Mode Adhesive 577E to 1004-AP
1	40	65.5	100%
2	"	80.8	"
3	"	65.3	"
4	"	68.2	"
5	"	52.1	"
	$\bar{x}$ 66.4 SD 10.2		
1	150	57.0	100%
2	"	72.1	"
3	"	45.4	"
4	"	50.0	"
5	"	50.1	"
	$\bar{x}$ 54.9 SD 10.5		
1	350	32.0	100%
2	"	29.5	"
3	"	42.7	"
4	"	46.8	"
5	"	42.4	"
	$\bar{x}$ 38.7 SD 7.5		

TABLE 21. BOND STRENGTH TEST MATRIX

Substrate	Number of Butt Tensile Tests at Temp 40°F	75°F	150°F	250°F	350°F
SIP/RTV-560/RTV-560E	3	3	3	3	3
SIP/RTV-560/RTV-577E	3	3	3	3	3
RTV-560/RTV-560E			3		
Tile (Machine Surface) to RTV-560E	3	3	3	3	3
RTV-577E	3	3	3	3	3

TABLE 22. BUTT TENSILE TESTS - RTV 560E BOND TO SIP/RTV

Specimen No.	Temp. (°F)	Break Stress (psi)	Failure Mode: Adhesive - 560E to 560 SIP Coating	Failure Mode: Cohesive - SIP
2	40	27.2	100%	0
7	"	41.8	10%	90%
12	"	29.7	0	100%
		$\bar{x}$ 32.9 SD 7.8		
1	75	25.0	100%	0%
6	"	27.5	90	10
11	"	32.7	0	100
		$\bar{x}$ 28.4 SD 3.9		
5	150	23.8	100%	0%
10	"	28.1	0	100
15	"	24.3	75	25
		$\bar{x}$ 25.4 SD 2.4		
3	250	19.7	100%	0%
8	"	26.6	20	80
13	"	20.1	0	100
		$\bar{x}$ 22.1 SD 3.9		
4	350	18.5	100%	0%
9	"	22.4	90	10
14	"	20.0	100	0
		$\bar{x}$ 20.3 SD 2.0		

TABLE 23. BUTT TENSILE TESTS - RTV 577E BOND TO SIP/560

Specimen No.	Temp. (°F)	Break Stress (psi)	Failure Mode: Adhesive-SIP to 560 coat	Failure Mode: Adhesive-577(E) to 560
2	40	36.0	15%	85%
7	"	32.9	2	98
12	"	28.9	30	70
		$\bar{x}$ 32.6 SD 3.6		
1	75	35.7	95	5
6	"	33.7	70	30
11	"	28.3	40	60
		$\bar{x}$ 32.6 SD 3.8		
3	150	26.5	90	10
8	"	28.4	30	70
13	"	23.8	0	100
		$\bar{x}$ 26.2 SD 2.3		
4	250	19.8	10	90
9	"	22.0	10	90
14	"	21.2	80	20
		$\bar{x}$ 21.0 SD 1.1		
5	350	20.7	0	100
10	"	18.7	10	90
15	"	19.6	5	95
		$\bar{x}$ 19.7 SD 1.0		

TABLE 24. BUTT TENSILES - RTV 560E BONDED TO RTV 560

(RTV-560 cured 4 hrs @ 160°F, RTV-560E cured 24 hrs at R.T.)

Specimen No.	Strength (psi)	Failure Mode
1	137	100% adhesive, 560E to 560
2	79	100% adhesive, 560E to 560
3	99	100% adhesive, 560E to 560
4	97	100% adhesive, 560E to 560
5	83	100% adhesive, 560E to 560
$\bar{x}$ 99		
SD 23		

TABLE 25. BUTT TENSILE TESTS - RTV560E TO HRSI TILE

Specimen No.	Temp. (°F)	Strength (psi)	Failure Mode: Cohesive in Tile	Failure Mode: Cohesive in Tile (at interface)
4	40°	6.0	0	100
9	"	5.3	0	"
14	"	8.1	70	30
		$\bar{x}$ 6.5 SD 1.5		
10	75	4.0	0	100
15	"	5.3	0	"
6		*		
		$\bar{x}$ 4.7 SD 0.9		
3	150	11.2	0	100
8	"	16.5	0	"
13	"	13.3	0	"
		$\bar{x}$ 13.7 SD 2.7		
2	250	3.5	0	100
7	"	*	-	-
12	"	4.8	0	100
		$\bar{x}$ 4.2 SD 0.9		
1	350	5.4	0	100
5	"	3.5	0	"
11	"	2.5	0	"
		$\bar{x}$ 3.8 SD 1.5		

*-Failed while loading onto grips.

TABLE 26. BUTT TENSILE TESTS - RTV 577E BOND TO HRSI TILE

Specimen No.	Temp. (°F)	Break Stress (psi)	Failure Mode: Adhesive-577E to Tile	Failure Mode: Cohesive in Tile
2	40	23.5	0	100%
7	"	13.1	0	"
12	"	11.1	0	"
		$\bar{x}$ 15.9 SD 6.7		
1	75	3.6	0	100%
6	"	11.8	0	"
11	"	11.7	0	"
		$\bar{x}$ 9.0 SD 4.7		
3	150	12.0	0	100%
8	"	12.9	5	95
13	"	19.9	0	100
		$\bar{x}$ 14.9 SD 4.3		
4	250	10.9	0	100%
9	"	11.7	5	95
14	"	12.5	5	95
		$\bar{x}$ 11.7 SD 0.8		
5	350	10.4	100%	0%
10	"	8.6	50	50
15	"	15.1	0	100
		$\bar{x}$ 11.4 SD 3.4		

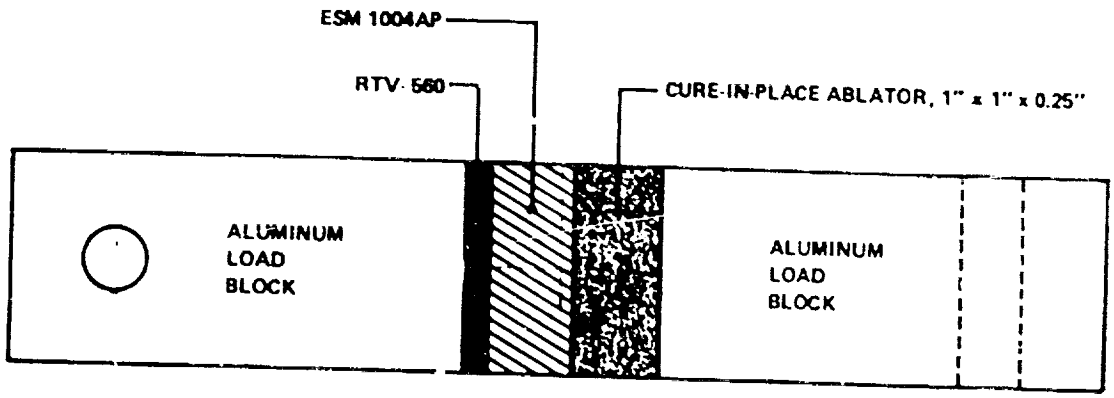


Figure 38. Test Specimen Butt Tensile (ESM/Cure-in-Place Ablator)

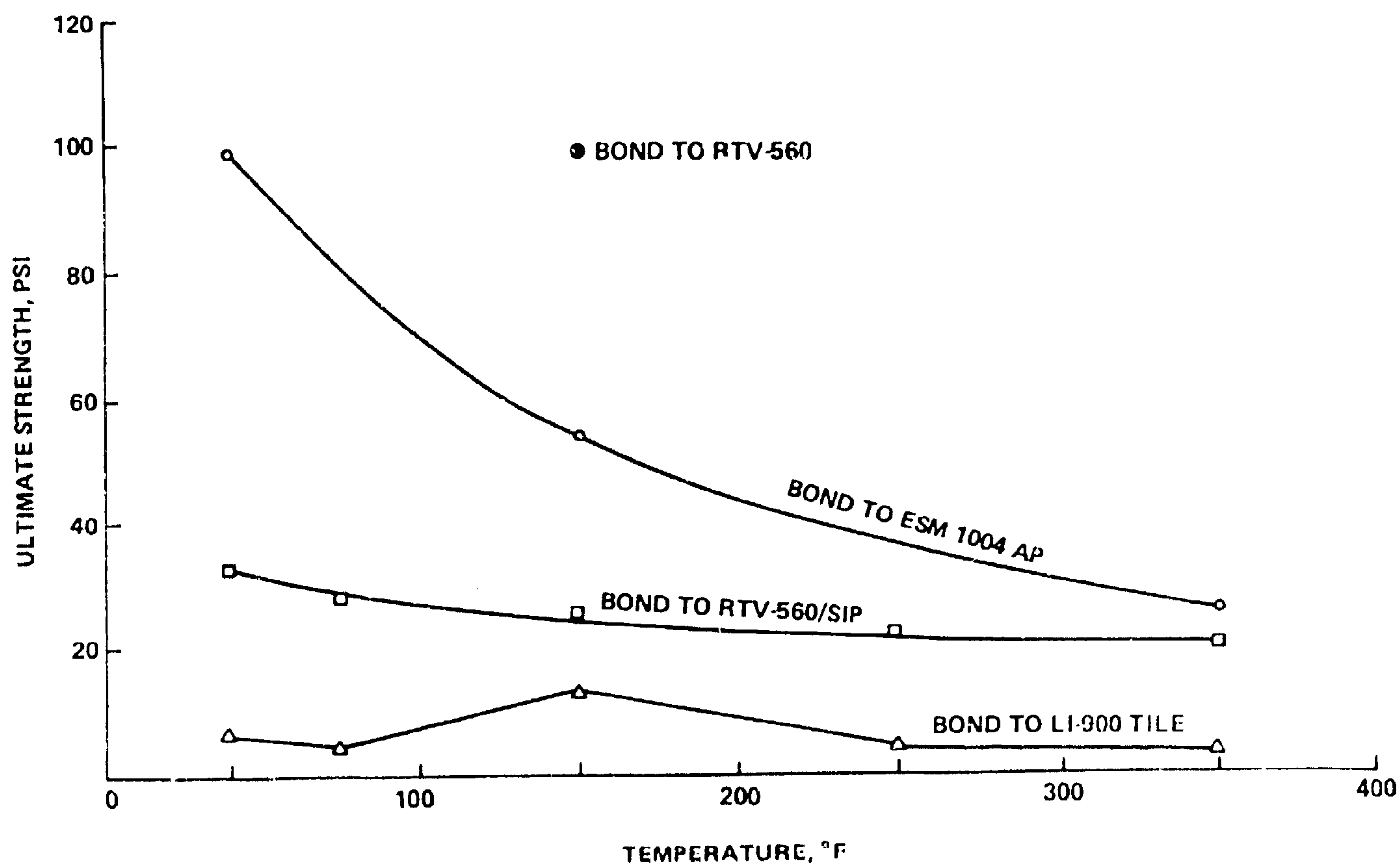


Figure 39. Butt Tensile Tests RTV-560E Blend

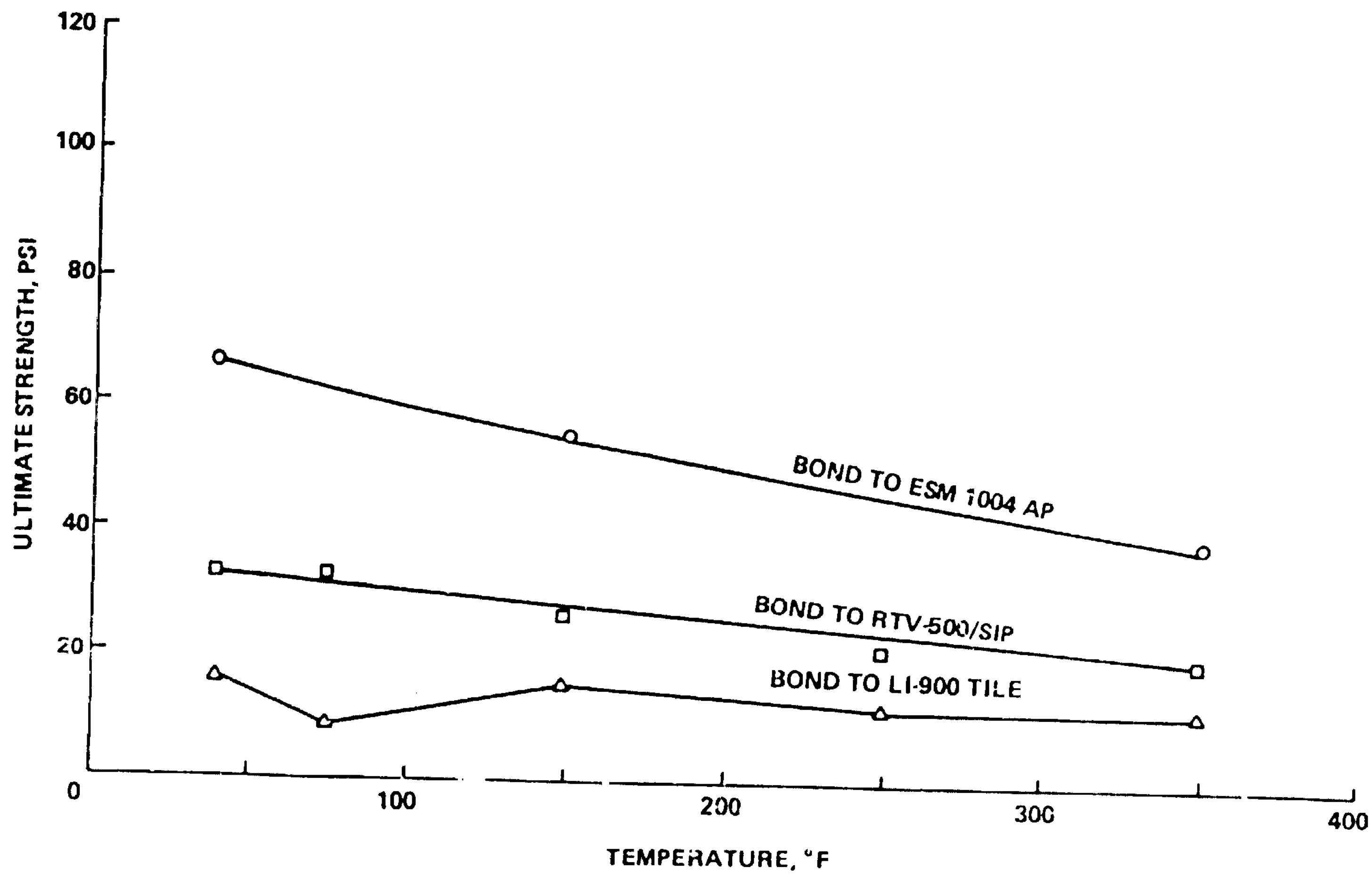
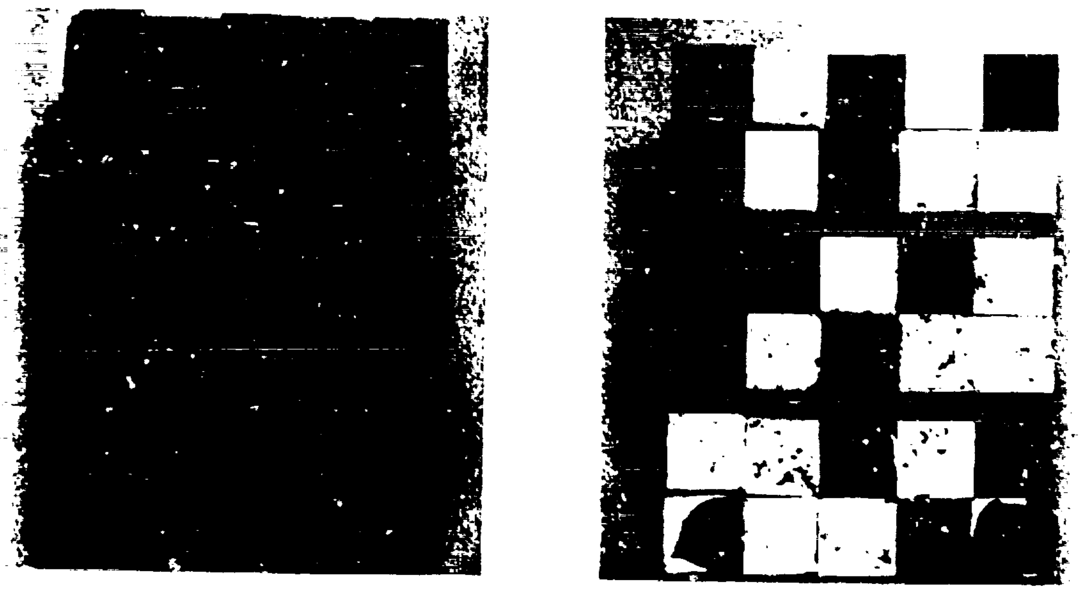


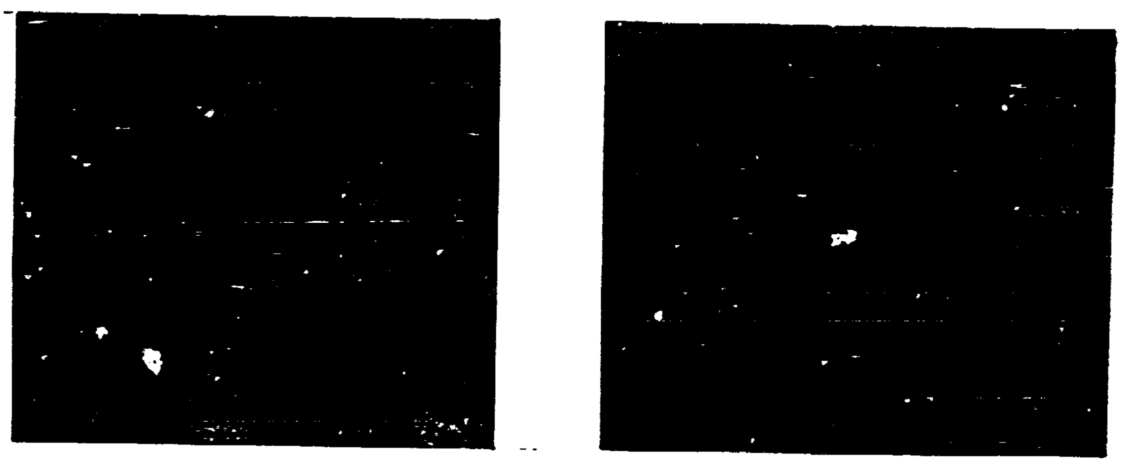
Figure 40. Butt Tensile Tests



RTV-560E/ESM 1004AP

RTV-577E/ ESM 1004AP

Figure 41. RTV-560E, RTV-577E/ESM 1004AP Post Test Butt Tensile Specimens



RTV-577E/RTV-560, SIP

RTV-560E/RTV-560, SIP

Figure 42. RTV-560/SIP Butt Tensile Post Test Specimens

RTV-560E/SILICA TILE

RTV-577E/SILICA TILE

Figure 43. RTV-560E, RTV-577E/Tile Post Test Butt Tensile Specimens

	ALUMINUM	ESM	RTV-560/SIP	TILE
FIRST STAGE BOND	SOLVENT WIPE GRIT BLAST WATER WASH AIR DRY PRIME	VACUUM SOLVENT WIPE DRY	VACUUM (BOND SIP SIDE)	180 GRIT SAND VACUUM

BOND WITH RTV-560
ROOM TEMP. CURE

	ALUMINUM	ESM	RTV-560/SIP	TILE
SECOND STAGE BOND	SAME	VACUUM	SOLVENT WIPE RTV-560 (REMOVE FINGER PRINTS)	180 GRIT SAND VACUUM

BOND WITH 1/4 INCH REPAIR MATERIAL
TEST AT 24 HOURS

Figure 44. Bond Test Preparation Flow Plan

4.4 REPAIR KIT

The objective of this task was to establish requirements and perform a conceptual design of the repair kit with major emphasis on the development, fabrication, and evaluation of a dispenser mechanism for applying the cure-in-place ablator. The repair kit is comprised of the dispenser, ablator materials (pre-cured and cured-in-place), other tools and preparation materials, the thermal control equipment and the storage container which interfaces mechanically and electrically with the shuttle and/or shuttle/EVA work station (s) to be defined by NASA. As part of this task, a very limited scope assessment of the container, its thermal control approach, and a preliminary weight estimate was performed. Other tools and items required for the repair kit were not specifically studied; however, some specific needs and approaches evolved from consideration of repair procedures.

4.4.1 DISPENSER CONCEPTS AND TRADE OFFS

The objectives of this task was to screen a broad range of possible dispenser concepts, examine two in more detail, and then select one for design and evaluation. The dispenser design effort was conducted in parallel with the cure-in-place ablator development task. The candidate resins/catalysts/fillers (discussed fully in Paragraph 4.3) encompassed an extremely broad range of viscosities and formulations (see below) which lent an extra measure of complexity to the concept formulation and breadboard design tasks.

CANDIDATE RESIN MIXTURES

RESINS	VISCOSITY (POISE)	CATALYST WT RATIO	DILUENT WT RATIO
RTV 560	50,000		
RTV 560E	140,000		
RTV 577	500,000		
RTV 577E	1,500,000		
CATALYST			
S.T.O.	Stannous Octoate	0.1-1.0%	
DILUENT			
SF 96-50	Silicone Fluid		1-10%

The evolution of the dispenser concept, as will be discussed in following sections, occurred in the following sequence.

- Screening
- Select Two
  - Static Mixer (Flow Mixer)
  - Batch Mixer
- Evaluate Above
- Select One Concept
  - Static Mixer
  - Small Disposable (100-125 $in.^3$)
- Design Static Mixer
- Design and Fabricate Breadboard
- Review Concept at Mid-Term Meeting
- Convert to Large Static Mixer (independent of later NASA direction to do same)
  - ~ 400 in^3
  - Throw away Mixer/Nozzle
- Provide Wood M/U to JSC & Review
  - Make Mixer part of body
  - Astronaut handles Hose/Valve/Nozzle only
- Accumulate Breadboard Test Data
- Eliminate Throw Away Mixer/Nozzle by:
  - Extending working time
  - Possible flushout if needed
- Design fabricate and test large prototype
- Final recommended solution
  - 40, in^3 dispenser
  - Tank & Mixer with Hose/Valve/Nozzle
  - No throw away parts required
  - Verified by prototype test data.

Concept Formulation and Description

The various mixing and application concepts can be divided into two basic categories. In the first, the resin and catalyst are first thoroughly mixed together, and the mixture is extruded thru a nozzle into the repair area. In the second category, the catalyst and resin, in measured ratio are forced through a mixing device to the nozzle and onto the repair area. A schematic of the static mixer concept is shown in Figure 45.

Table 27 lists some of the concepts initially considered, and some general comments as to their suitability. These were narrowed down to two: one the axial piston batch mixer; and second, the continuous flow/mixer. Conceptual designs of each are described below.

Concept No. 1 - The mix and extrude concept is illustrated by the design depicted on Figure 16. The resin is stored in a chamber which incorporated the cylinder, a mixing and expelling piston assembly and a lead screw. The piston consists of two members both having a pattern of holes passing thru them. The upper member is permanently fastened to the operating rod (and handle). The lower which also has paddle like vanes, is fastened by a bearing to the upper member and rides on the lead screw. The catalyst is introduced either from a ruptur-ing bag stored in the pistons or by an external syringe inserted hypodermically thru a rubber plug in the upper cap. Mixing is accomplished by moving the piston up and down. The resin mixture is forced thru the holes in the pistons while it is further agitated by the rotation of the lower piston and its vanes. Extrusion of the mixture is accomplished by pulling the piston fully up and then rotating it clockwise. A ratchet between the two pistons locks them in a relative position so that none of the holes in one piston align with those in the other. The pistons are driven down by the lead screw. This conceptual design requires that mixing and extrusion power be manually supplied by the operator.

Concept No. 2 - The mix during extrusion concept is illustrated by the design depicted in Fig-ure 47. Two cylinders are arranged concentrically; and the piston areas are in the required volumetric ratio of the catalyst and the resin. The pistons are directly connected to each other thru a tower arrangement. Pressurizing the upper side of the resin piston drives both pistons downward. This action feeds catalyst and resin, in the correct proportion, to a labyrinth type static mixing assembly. This assembly consists of corrugations welded to-gether in a series and alternately crossed to provide many repeated divisions of the flow pattern to provide good mixing. Flow is controlled by a valve placed between the mixer and the nozzle. The two basic concepts are compared in Table 28.

Other second tier trades that were conducted are described below.

a. Manual vs. Automatic Operation — Although the astronaut is capable of performing various tasks, it was considered that an automatic or at worst semi-automatic dispensing system should be utilized.

b. Electric vs. Pneumatic Power — The decision to use the MMU EVA concept negates consideration of electric power unless from batteries included with the dispenser. Pneumatic power was selected for performing the automated mixing and dispensing functions. The specific source of pneumatic power is still under study:

1. Compressed gas blow down and regulator
2. Multi-phase vapor boil-off.

C-2

c. Piston vs. Bladder Expulsion — The piston method for expulsion is far simpler than a bladder method (fabric or metallic) especially when a pass-thru for mechanical mixing/stirring must be provided.

d. Flow Control - Metering Valve vs. Pressure Control — A metering flow control valve at the nozzle is a more positive method of control and was selected over controlling extruding pressure.

4.4.2 SELECTED MIXER-APPLICATOR APPROACHES

The "mix during extrusion" static mixer concept was chosen for its greater simplicity and operating flexibility. This concept permits the use of small "throw-away" dispensers, or a large dispenser with "throw-away" mixer-nozzle assemblies. As an alternative to the throw away mixer-nozzle, the mixer-nozzle assembly can be kept clear over an extended period of time well in excess of the pot life by scheduling periodic flowing of the mixture to avoid setting up in the mixer or nozzle. This latter scheme trades "wasting" material in lieu of requiring operator assembly/disassembly functions and carrying spare mixers to the work site. Since the later also wastes material, the spare elements actually provide no advantage.

Thus the trade off studies resulted in the adoption of a pneumatically operated, continuous flow system using a static mixer. The pneumatic actuator continuously meters out resin and catalyst in the proper proportion into the mixer. The static mixer will reliably mix whichever material is selected and continuously dispense it upon operation of the flow control valve. The only parameters that must be selected are the operating pressure and mixer size which are a function of the material selected and flow rate required. (This is discussed in detail in the following paragraph.)

An advantage which occurred from this selection was the capability of offering various options of the concept:

a. Small throw-away type dispenser.

b. Large dispenser (>1 gal. capacity) with a replaceable mixer-applicator.

c. Large dispenser (>1 gal.) which when coupled with a slower gelling material, will be operable for longer periods of time, at worst requiring self-flushing with a fresh mixture of material.

The breadboard design was based on (a), a wood mockup provided to NASA during the 6th week of the program was based on (b), and subsequent design and prototypes were based on (c).

4.4.3 BREADBOARD DISPENSER DESIGN FABRICATION, AND EVALUATION

Design

The Design objective of this task was to design the breadboard dispenser model. Sketches of the dispenser parts and assembly were prepared of sufficient detail to permit fabrication and assembly. The breadboard dispenser readily disassembled for cleaning after each batch and prior to setting up of the mixture. Single point failure and redundant features were not incorporated in the design. The design was capable of being operated in a vacuum over a temperature range of 40-120°F.

The ability to vary catalyst ratio was incorporated into the design, and parts procured accordingly. However, prior to assembly, the catalyst ratio was fixed at approximately 10%, and the design modified to accommodate this ratio. The breadboard dispenser was sized to deliver approximately 100 in.^{3}. It incorporates the concept as shown in Figure 47, except that it utilizes standard 72 ft.^{3} compressed gas bottles and adjustable pressure regulator for actuation and rough plumbing and valves. The key features are real, namely the dual cylinders and the static mixer.

Fabricate Breadboard Dispenser

The object of this task was to fabricate and assemble one dispenser to the sketches prepared in the previous task. Parts were manufactured and assembled in the prototype shop. Identification and procurement of long lead items was expeditiously accomplished, and the fabrication completed on time. The concentric piston dispenser and the static mixer parts are shown in Figure 48. The pistons with their rods, the metering tube, which separates the resin and catalyst and the end plates was made of 6061 aluminum and the outer cylinder of PVC pipe.

All static and dynamic seals employ nitrile (buna-N) O rings; and the end plates were held by full length tie bolts. Twelve element mixer assemblies were selected to mix the viscous material. These included a one inch diameter unit having 1/8 corrugations, a 1-1/2 inch diameter unit having 1/4 inch corrugations and a 2 inch diameter unit also with

1/4 inch corrugations. The housings are simply stainless steel pipe. The design and fabrication tasks included the test set up. Initial problems with loading the RTV, especially the more viscous 577 series resulted in significant air being entrapped in the loading process, in addition to that inherently trapped during mixing. Alterations to the set up, plus deaerating the material for a minimum of 4 hours have helped solve the problem. Essentially, the degassed resin is "gravity" fed from the supply container into the storage cylinder, with the piston in the retracted or fully loaded position. A vacuum pump is connected to a purging port in the cylinder and resin drawn in. When resin begins to enter the vacuum line (short piece of Tygon), the vacuum is turned off. The inlet valve is shut off, and the piston pressurized (10-20 PSI), if it moves forward and springs back upon pressure venting, then air is entrapped. The piston is pressurized again, and the inlet valve opened to purge out air.

TABLE 27. MIXING CONCEPTS CONSIDERED

Concept	Comments
Rotating Paddle	• Difficult to Mix-Must Wipe Total Surface • Difficult to Expel Around Paddles • Limited to Batch Mixing • Long Mixing Times
Axial Piston	• Better Mixing Than Above • Requires Push/Pull Motion • Secure Mixing Piston & Start Eject Piston (Crewman)
Mixing Chamber	• Difficult to Mix Wide Ratios • Continuous Flow Capability - Easier
Static Mixer	• Proven Design for Large Mix Ratios • Proven Design for Large Viscosity Ratios • Continuous Flow-Easier
Premix & Store @ -40°F Micro Balloons	Untried Methods

TABLE 28. MIXER COMPARISON

Mix and Extrude	Mix During Extrusion
	Advantages
• Extrusion pressure is lower.	• Simplicity.
	• Little operator effort.
	• Operating flexibility - Pot life applicable only to resin in mixer and downstream.
	• Large storage unit can be used with replacement mixers.
	• Reliable mixing of large resin/catalyst ratios (both volumetric and viscosity) have been demonstrated.
	Disadvantages
• High viscosity resin makes mixing energy high.	• High pressure required for mixing and extrusion.
• Entire mix has single pot life	• Container is a pressure vessel.
• Large operator effort during mixing.	• Reliable homogeneous mixing of large resin/catalyst ratios (volume and/or viscosity) require longer and/or larger mixer elements.
• Introduction of catalyst requires a separate step.	
• Homogeneous mixing of large resin/catalyst ratios requires long mixing time.	
• Homogeneous mixing of large resin/catalyst viscosity ratios requires long mixing time.	

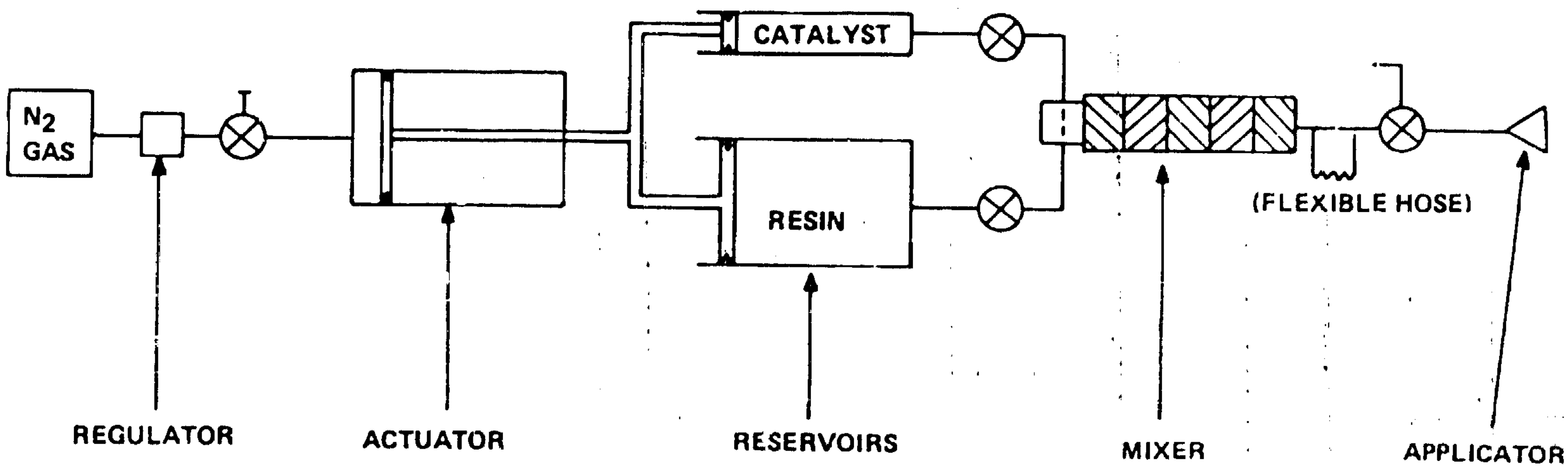


Figure 45. Static Mixer Concept Schematic

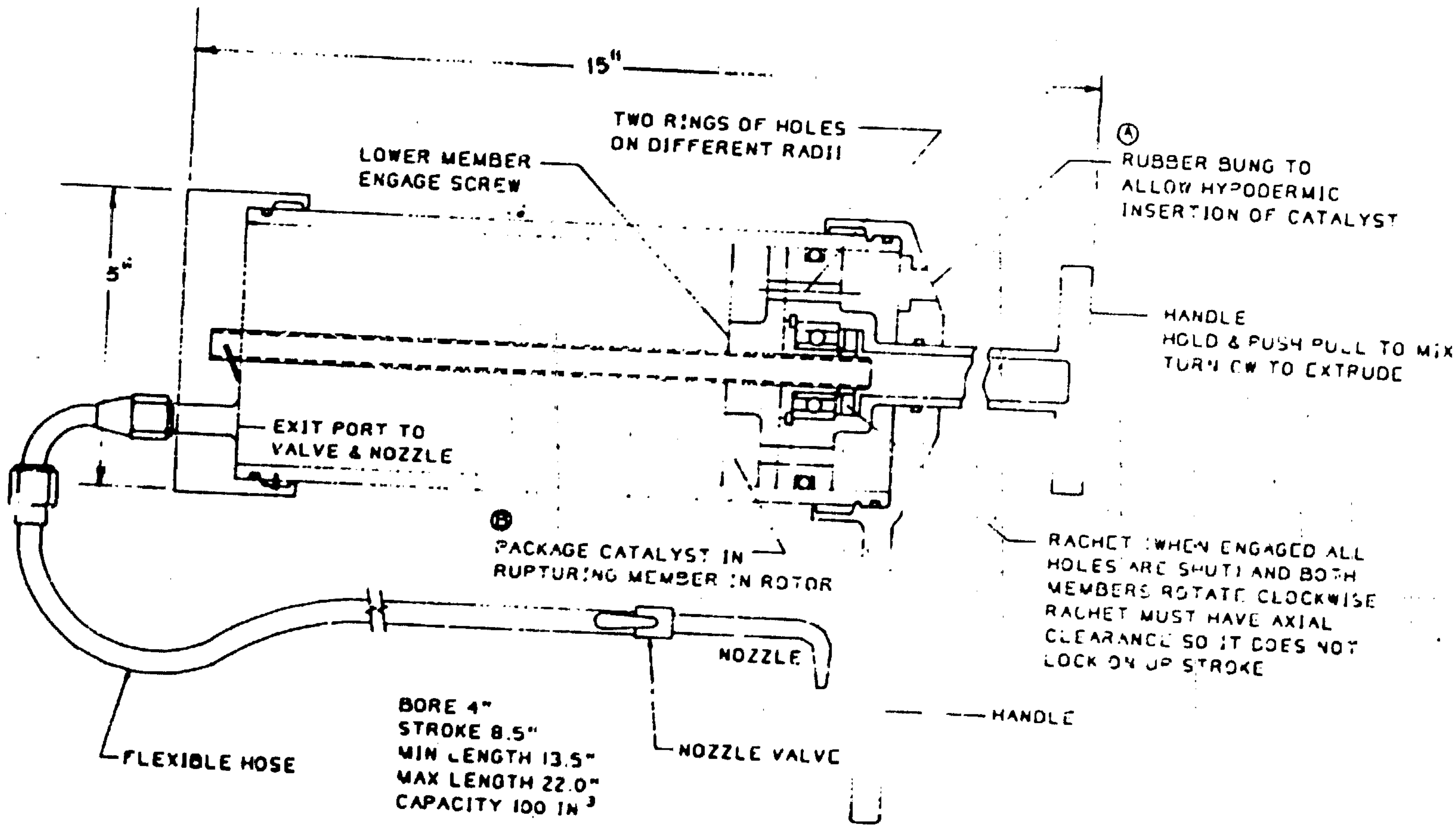


Figure 46. Dispenser Concept #1 - Manual Reciprocating Mixer

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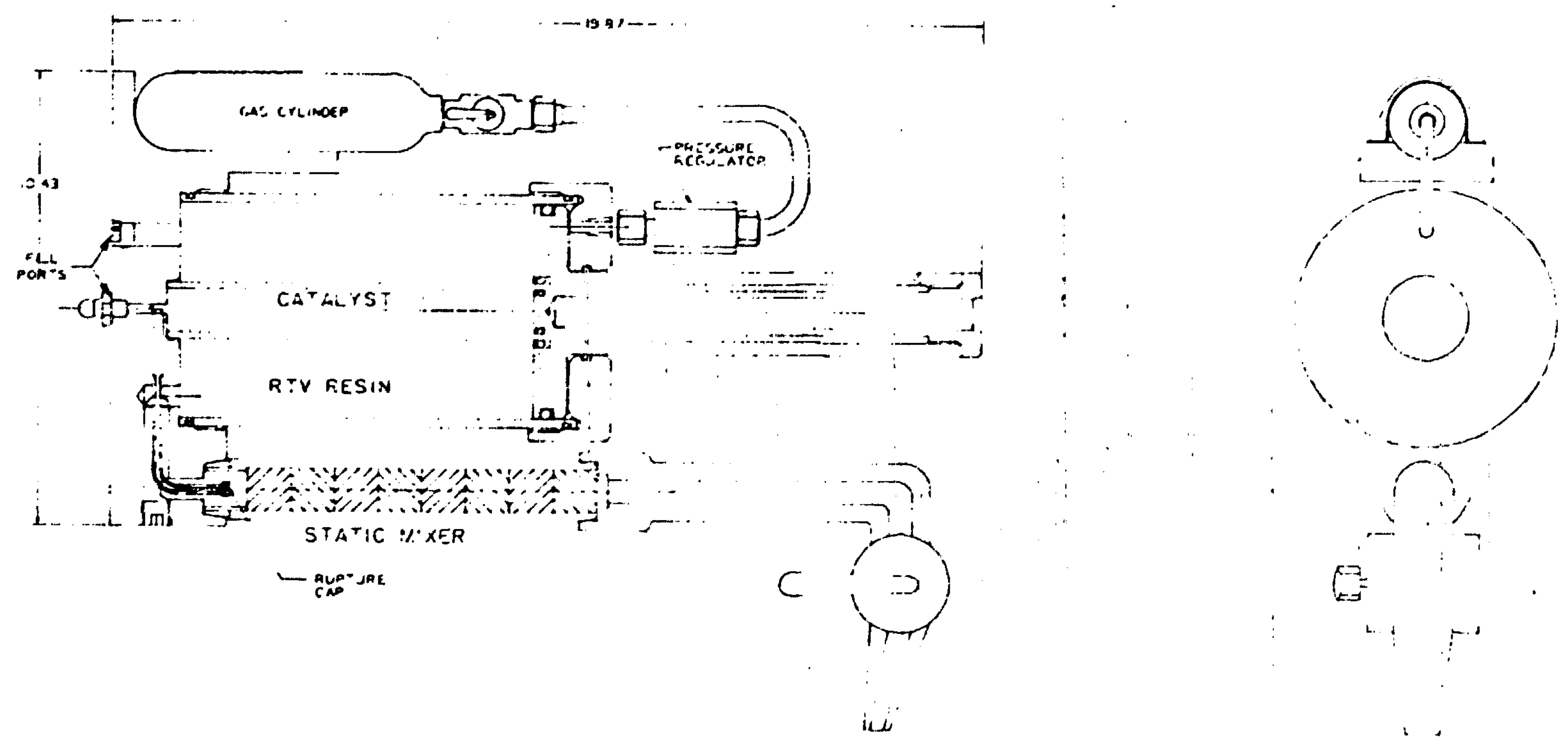


Figure 47. Static Mixer Dispenser Concept

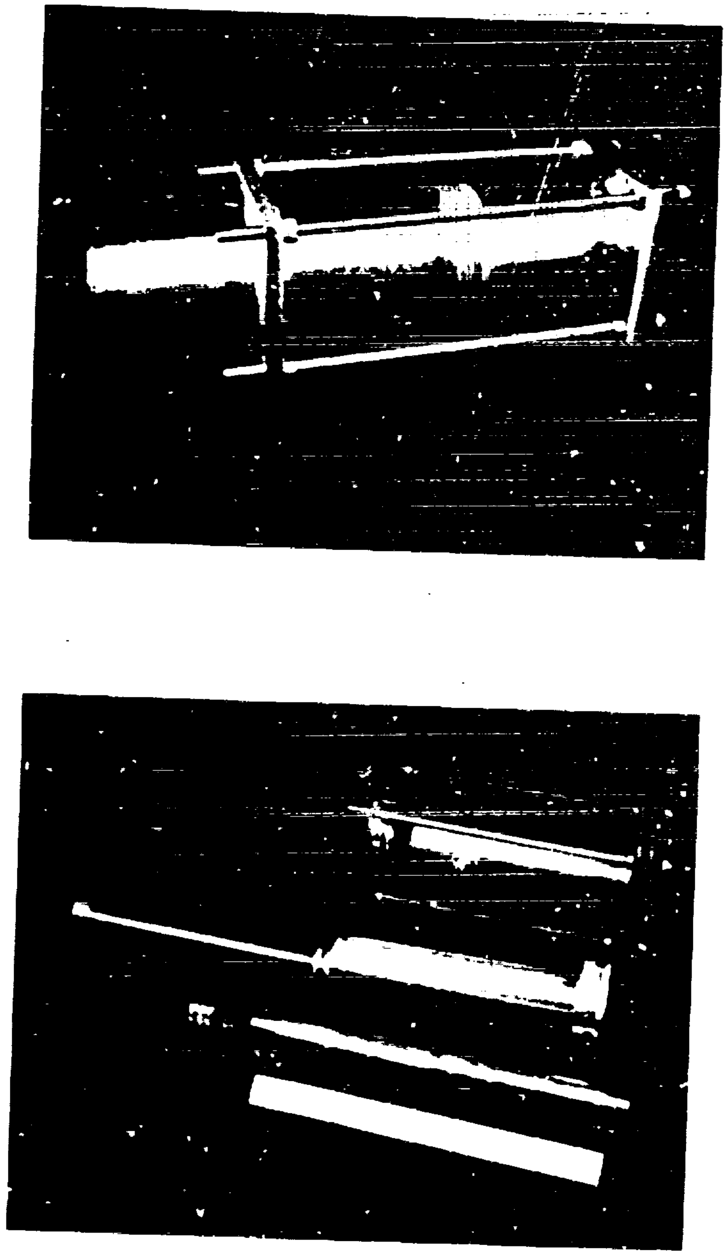


Figure 48. Breadboard Dispenser Parts Photographs

4.4.4 PROTOTYPE DISPENSER DESIGN AND FABRICATION

As a result of interaction of the mid-term meeting, a decision was made by GE to emphasize and proceed with a large "3 part" dispenser as compared to a small disposable device.

Mockup Unit

Prior to proceeding with the prototype design and fabrication, a wood mockup unit was prepared. This unit as shown in Figure 49 was delivered to NASA JSC during the 6th week of the program. The mockup was reviewed with NASA personnel for operational effectiveness. The major change which resulted from the interchange was to make the mixer assembly part of the dispenser body so that the astronaut only handles the hose, trigger valve, and nozzle.

Functional Prototype Design

The prototype dispenser unit is designed to be representative of a flight design where the required 1080 cubic inches to be deliverd will be packaged in three large dispensers. The capacity is nominally 400 in.^{3} which is the required 360 in.^{3} plus the unavailable residual volume of the mixer and nose/valve/nozzle assembly.

The structure is designed primarily to permit quick construction consistent with the early demonstration in zero - g flight. Stress levels were kept low to minimize the risk of fabricating parts before or at the same time as they were stress analyzed. The prototype is functionally identical to the flight item but considerably heavier due to the above constraints.

The prototype dispenser is shown in Figure 50 comprises a concentric two piston reservoir; a pressurant tank with fill and shut off valves, and a regulator; a static mixer assembly connected to the reservoir and a hose, valve, and nozzle assembly which provides flexibility for applying the "cured in place" ablator-adhesive to the repair area.

The twin piston reservoir assembly is sized to displace 360 in.^{3} plus the volume required to fill the mixer and hose-nozzle assembly, estimated at 47 cubic inches. The two sets of pistons and cylinders are arranged concentrically with the catalyst (10% by volume) piston in the center and the annular resin cylinder on the outside. All static and dynamic seals employ nitrile O-rings. The structure was designed to contain the highest extrusion pressure, which prior to testing was estimated at 500 psi. The design was targeted at a burst pressure of four times this value or a 1.25 x the pressurizing tank pressure.

The pressurizing tank was sized to allow operating at relatively low pressure. The pressure was chosen to allow the above described structure to have a 1.25 burst pressure ratio without an unacceptable structural penalty. The nominal pressure was set at 2000 psi, which resulted in a required volume of 139 in^3. This requirement was satisfied on a very short procurement basis by a Pressed Steel Tank Co 3RC 150 HT3 tank of 150 in^3. This tank meets DOT 3HT-3000 requirements which rates it for pressures up to 3000 psi when used in aircraft. The pressurant is N_2 and the operation is initiated by opening a quick operating valve. The dispenser pressure is controlled by a regulator having a built in relief valve.

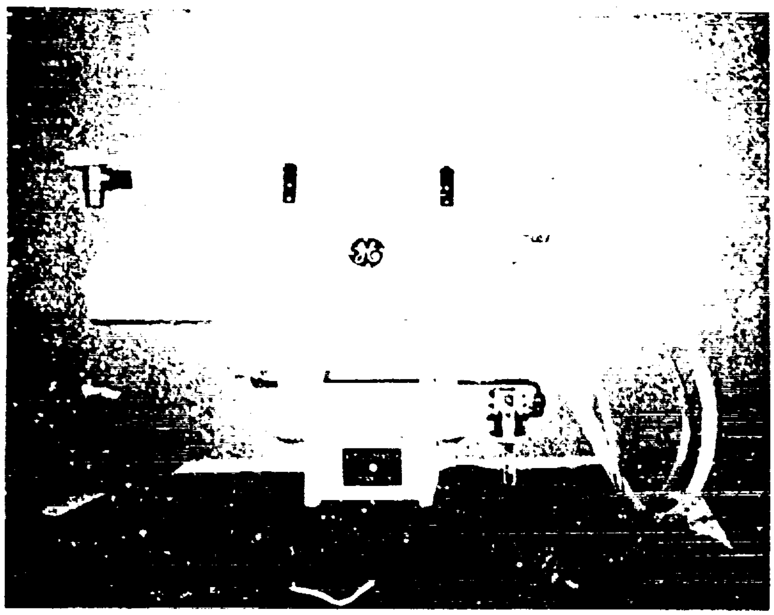
Static Mixer — The key element of the entire concept is the static mixer. This comprises a tube containing a device which compels the working substances to travel random labyrinth paths and thus become mixed together. The pipe contains a number of elements, each of which is a diameter long. Each element comprises a number of layers of corrugated steel welded together in a crossed diagonal pattern. The elements, in turn are welded into pairs at right angles to each other. Twelve elements or six pair were initially selected. The corrugations of various pitches are also available. One, one and one-half, and two inch mixers were evaluated to determine the size and number of elements required for adequate mixing and minimum pressure drop.

Hose, Valve, and Nozzle — The mixer is connected to the valve-nozzle assembly by a four-foot length of flexible hose. The hose must be capable of withstanding full pressurization pressure and must provide an adequate flow path. A nominal 3/4 inch size, Aeroquip 2208, double braid, teflon line hose has been chosen for this requirement. This hose offered the best flexibility and lowest weight of the high pressure hoses. Its burst strength of 8,000 psi is far in excess of requirements.

The initial choice of valve is a 3/4-inch plug valve in which a cylindrical plug, containing a full flow passage, is rotated 90 degrees off to full on. A "Circle Seal" valve is being modified to provide a simple hand grip squeeze dead man type of shut off. The nozzle is simply a transition section to fan the full flow of the 3/4 in line into a 0.19 x 1-1/2-inch flat strip. Initial design and testing of this design has shown various shortcomings which need to be corrected, or other concepts must be evolved.

An alternative to this valve is to locate the valve at the exit of the mixer proper. Thus, the hose does not need to be a high pressure design, and a more flexible and manageable configuration would result. However, the crewman must operate the valve with one hand while still maneuvering the nozzle. The most acceptable approach can be determined during each astronaut training.

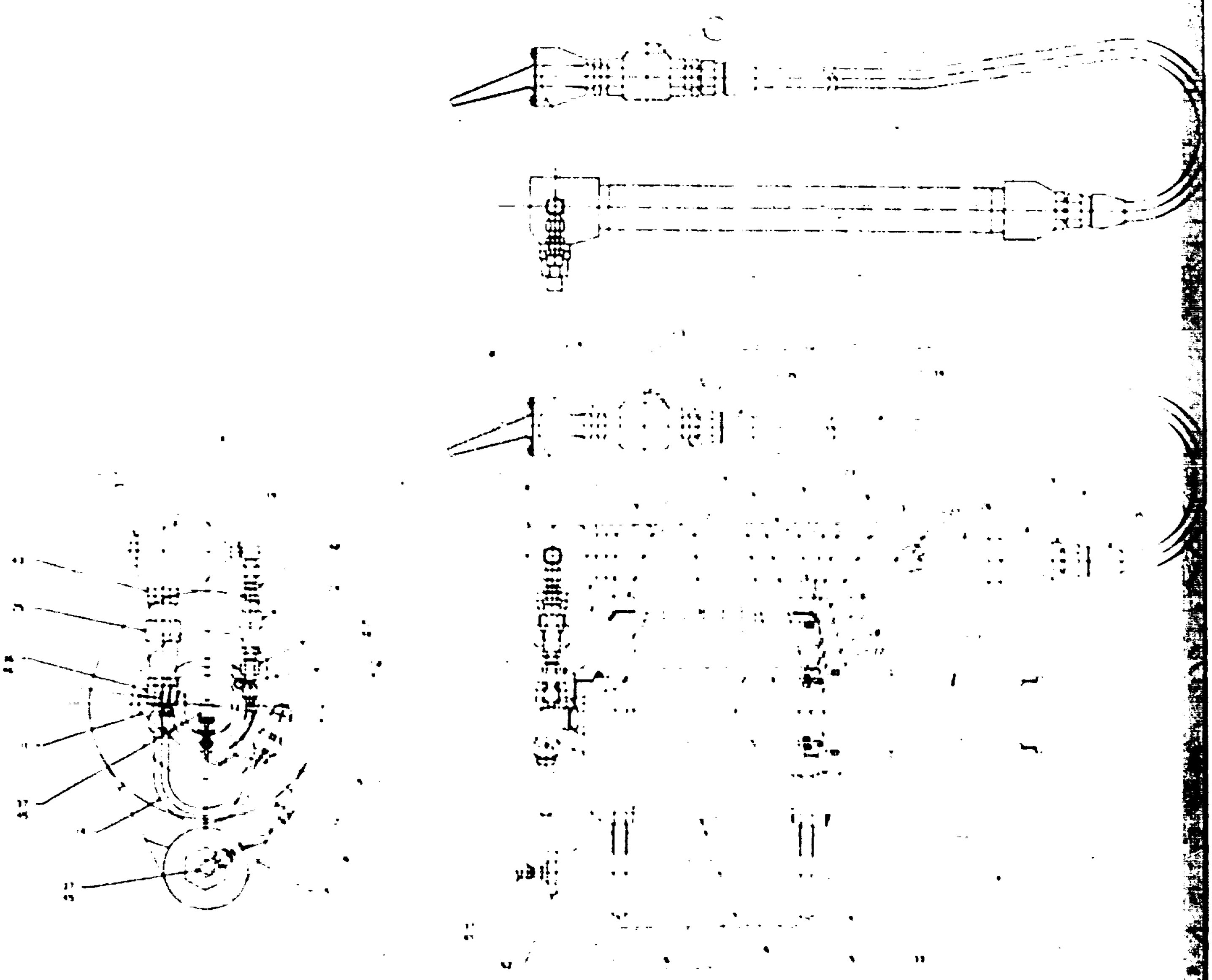
The prototype unit was fabricated to the definition of Figure 50. The completed unit is shown in Figure 51 after several tests, the prototype unit was provided to NASA-JSC for a KC-135 zero-g test with a fully suited astronaut. Results of this test were not available for the final report, however the demonstration of the unit and crewman training at NASA-JSC prior to the test was very successful.



- DELIVERED TO NASA DURING 6TH WEEK OF PROGRAM

NOTE: VALVE NOT MEANT TO SIMULATE REAL VALVE AND NOZZLE

Figure 49. Wood Mockup



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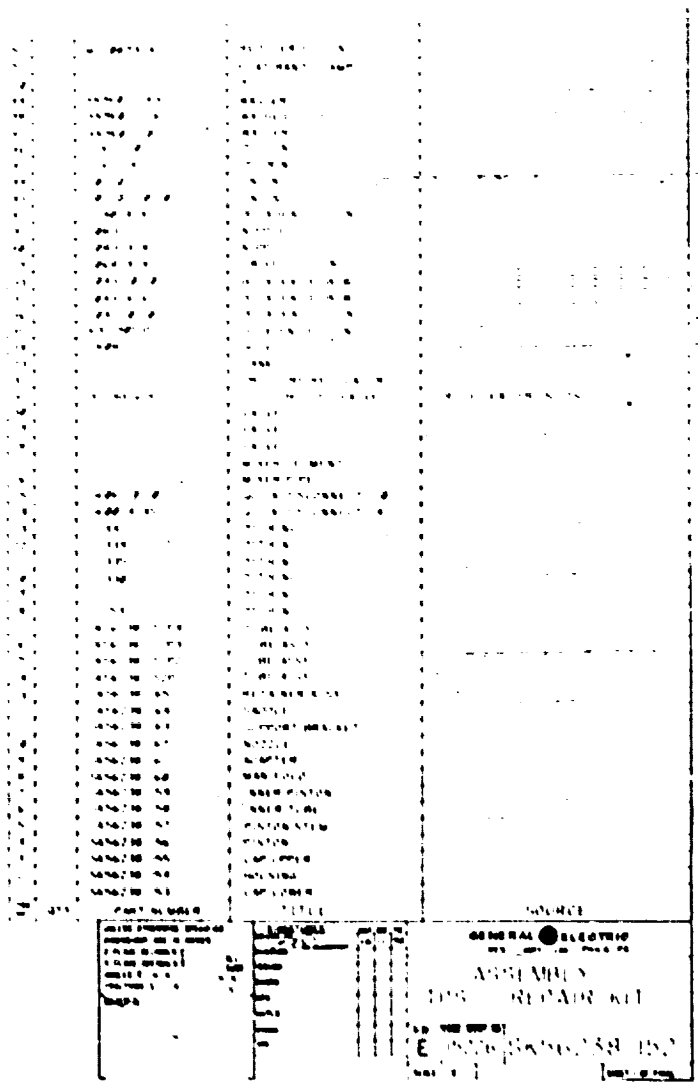
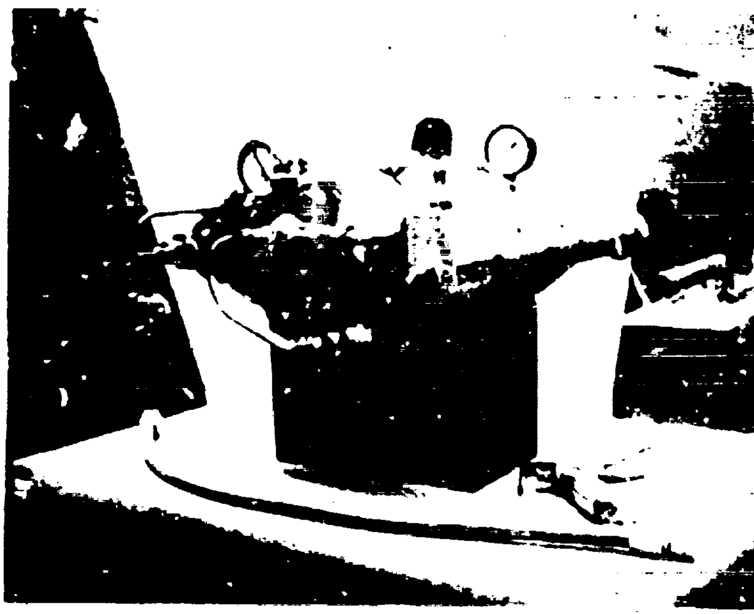


Figure 50. Functional Prototype Drawing



- DELIVERED TO NASA DURING 9TH WEEK OF PROGRAM
- USED FOR KC-135 ZERO-G TEST

Figure 51. Functional Prototype

4.4.5 TEST AND EVALUATION OF BREADBOARD AND PROTOTYPE DISPENSERS

Breadboard Dispenser Checkout

Cylinder Assembly – The cylinders and pistons were assembled and leak tested at low pressure. Rework was accomplished on the outer cylinder ID (PVC pipe) to correct leakage problems. Subsequent to this, the assembly was proof tested to 380 psi, the nominal working pressure of the pipe. For lab testing, an upper limit pressure of 350 psi was established.

Dispenser Assembly – The entire dispenser was assembled by interconnection of the cylinder assembly to the static mixer and to the filling pressure pot. This piping installation was modified several times to correct filling deficiencies. The entire assembly was hydrostatically proof tested to 380 psi.

A trial run was made using a water soluble spackling compound with an apparent viscosity slightly lower than RTV-577, and using water in the catalyst chamber. The unit was pressurized at 100 psi. The material flowed erratically (entrapped air) although with a fairly well mixed consistency (lower viscosity, of course). This trial run gave the first indication that loading procedures had to be refined (accomplished), subsequent paragraphs discuss the test series as tabulated on Table 29.

Breadboard Test Results

Test Series "A" – This series utilized a 12-element (6 pairs) 1-inch diameter mixer, based on preliminary analyses for the material viscosities to be used. Materials tested were RTV-560E and 577 blended ("E") and unblended, and with and without catalyst. The basic goals of this series were to obtain flow data and mixing efficiencies for the various materials, which represented a very wide range of viscosities. An early test run using RTV-560 as the "catalyst" in order to obtain visual indication of mixing showed excellent results with both 12 and 10 elements (6 and 5 pairs) (see Figure 53). The addition of blend increased the pressure required for flow, while the addition of 70% diluent (with/without hardener) increased flow rate ≈ 1.6 times for any of the materials tested. Some unexpected results were observed as listed below:

a. 577E and 560E appear to flow at the same rate at high pressure >250 psi – most likely due to the increase in thixotropic behavior of the basic 577.

b. RTV-577 flows better than 560E which is 1/3 as viscous, most likely for the same reason as above.

c. All materials tested behaved with an apparent viscosity much lower than the predictions for laminar flow at low flow rates of the "calculated" newtonian fluids.

These results are plotted on Figure 52 showing good behavior with the flow rate proportional to pressure. The calculated flow data for newtonian fluids is also shown for comparison. A pressure gage in the manifold block at the entrance to the mixer was used for pressure drop measurements in the mixer unit. The ΔP appeared to be 25–40 psi range at the 5-10 in^3/min rates. However the accuracy of the data was coarse because of clogging and partial curing of material in the gage and its port. No further attempts were made to instrument the flow (cylinder pressure was used). Flow measurements were made by collecting a weighed sample over a timed run.

Mixing effectiveness was evaluated visually and by hardness measurements. Hardness measured about 55 ± 10 durometer for specimens catalyzed, and was quite uniform throughout any one specimen. All specimens were cured at room temperature. One half inch long sleeves were inserted at the 4th and 5th mixer pair exits to measure hardness on one run with RTV-577. These coupons measured 40 and 50 durometer respectively.

During the last test run of this series, made in the presence of Dr. Leger, NASA-JSC, two tile cavities were filled, one with RTV-560E and one with RTV-577E. The cavities had gaps to simulated adjacent tiles of 0.060 and 0.12 inch, in order to determine if the material would flow into them. The 560E did partially flow into the gaps, whereas the 577E was confined to the basic cavity. The mold line restoration or leveling technique using a plastic sheet was also demonstrated. Set times were about 2 hours for RTV-560E and about 30 minutes for 577E.

Test Series B — This series was conducted using the 1-1/2 x 1/4 inch cell mixer in order to increase flow and reduce pressures. It also included the use of black dye (Nigrosine) in the catalyst as a visual indicator. The test with 6 pairs (12 elements) showed poor mixing. Therefore one more pair of elements was added, resulting in better mixing, but not sufficiently uniform to be considered good. Nonetheless, hardness measurements in both the

the light gray and dark gray areas representing low and high catalyst concentrations, indicated durometer readings in the 45 to 55 range. No flow data was recorded because of the "poor" mix.

<u>Test Series "C"</u> — This series attempted to combine the good mixing characteristics of 1-inch elements with the low ΔP characteristics of 1-1/2-inch larger cell elements. A two-stage mixer was configured, consisting of three 1-inch elements in series with five 1-1/2-inch elements, with the 1-inch elements at the inlet end of the mixer. The mixing was excellent and of uniform color throughout the entire pour and the flow rate exceeded 20 in^3/min at 250 psi.

In this test series, a pour was made into a hard vacuum, with the dispenser at ambient. Mixing was excellent again. The resin was deaerated with a roughing pump for ≈ 20 hours, prior to loading into the dispenser, and after the dispenser was connected to the vacuum chamber, the mixer and all downstream interconnections were also vacuated. A 3-inch deep container was filled and the flow observed thru a viewing port. The material was observed to outgas both visually and from the pressure (ion) gage on the vacuum chamber. The sample was removed after 44 hours of 10^{-5} torr vacuum. It had a fairly flat and uniform surface. Sections thru the material showed a closed cell structure with the cells fairly uniform in size between 1/8-1/4-inch in diameter. The material cured well (see photo in Figure 20).

<u>Test Series "D"</u> — This was an attempt to optimize flow/mix by reducing the number of elements to 2-1" x 4-1-1/2". Mixing was inadequate.

<u>Prototype Test Results</u>

<u>Test Series "E"</u> — Prototype Testing — This series was the first test of the prototype dispenser in preparation for the zero-g flight tests on a KC-135 airplane with a suited crewman.

The purpose was to obtain flow data, mixing effectiveness and flow vs. dwell time (working time). The 2 stage mixer was refined by removing one 1-1/2-inch element pair. The results showed excellent mixing and flow, although the flow rates were slightly lower than for the breadboard even though one element pair was removed. This was attributed to greater pressure drop in the dispenser prop .r because:

a. Larger mass being moved (1-1/2 gal. unit vs. 100 in^3)

b. Different plumbing configuration (more bends)

c. More force required to move larger pistons

The flow data is shown plotted on Figure 52, indicating that 20 in^3/min can be extruded at 250 psi.

The second part of the test, which was one continuous test run, was to let the catalyzed material sit in the mixer for a time period, and restart the flow catching a flow rate sample of about 1 in^3. The data shows that the material will flow at a constant rate after repeated dwell time periods of 15 minutes with ~ 0.2% catalyst (STO) to resin concentration.

The effect of reversing the mixer assembly (large elements at the inlet end) resulted in poor mixing.

Other Prototype Tests

As part of the flight certification, the storage container assembly was subjected to a hydrostatic pressure proof test of 1200 psi, first on the inlet (high pressure) side and then on the resin (low pressure) side. Photographs of the proof test are shown in Figure 53A and the Engineering Test Report is provided in Figure 53B.

Conclusions

The one inch diameter/six element pair tests all exhibited good mixing as determined by the absence of dye streaks in the effluent and by the uniformity of "Hockey Puck" samples. The pressure drop versus flow performance is shown in Figure 52 for various candidate materials. This plot also includes calculated performance for Newtonial fluids of various viscosities. The results show that the 577E viscosity was measured as 1,400,000 centipoises, while the test results suggest a value of 100,000 to 150,000 C.P. Since the material contains substantial amounts of three different fillers, the apparent non-newtonian behavior is not surprising.

The results with the 1-1/2-inch mixer showed that inadequate mixing took place within the 21" constraint in length. Therefore a two stage mixer was configured which provided the good mixing of the 1-inch elements with the lower pressure drops of the larger unit.

Hardness measurements of the various hockey puck samples collected during all of these tests showed a hardness of 45-65 durometer range after several days.

Overall, the tests have proven the effectiveness of the dispenser concept in mixing and operational characteristics. Extensive data has been accumulated for final dispenser design. A hybrid 2-stage mixer consisting of four 1-1/2-inch elements in series with three 1-inch element paris performs satisfactory and consistent mixing while extruding the material (577E) at a moderate pressure for a target flow rate of 20 in^3/min. The one test in a vacuum also showed excellent flow characteristics. The material cured with porous structure, but did not rise above the cavity. It is likely that the majority of the bubles were from entrapped air in the resin, which had been air blended and evacuated with a roughing pump (28" vacuum) for about 20 hours. A fully degassed material will most likely be less porous.

The dwell time tests demonstrated that the "3 part" dispenser as configured in our prototype design permits the utilization of the large container concept, enabling the crewman to use the mixer intermittently while performing other related repair tasks.

TABLE 29. BREADBOARD AND PROTOTYPE TEST RESULTS

A. 1" Mixer Elements (6 pairs except as noted)

Run	Purpose	Resin	[1]Catalyst	Pres. (psi)	Flow Rate in^3/min.	Remarks	Conclusions/Observations
1	1st Run	577E	.6%	300	4.5	Hardened in mixer < 5 min.	Good material flow, low flow rate at moderate pressure
2	Flow Rate	↓	None	140 255 305	3.3 4.9 6.2	Problem loading gun–entrapped air	Low flow rate. Flow rate linear with pressure Δ P piston to mixer inlet ~ 20 to 30 psi
3	Mixing Efficiency (Visual)	577E 577E	RTV 560 RTV 560	200 200	---	Well mixed-red color from start of run 5 element pairs well mixed.	Mixed RTV-577E with ~ 10% RTV-560 in catalyst chamber. Ran with 6 & 5 element pairs. Obtained excellent mixing as evidenced by uniform coloration. Photos of mixer elements (along side and end view) show mixing. (Fig. 53)
4	Flow Rate	577 ↓	None ↓	75 105 145	6.22 11.38 19.24	Entrapped air still a problem	Flow rates increase significantly over the blended RTV.
5	Flow Rate	577	.3% (Reduced amount of STO to permit easier cleaning of the gun)	145	31.1	Diluted catalyst improves flow. Obtained samples at 4th & 5th elements.	10% dilutant significantly improves flow rate. No difficulty in loading catalyst mixture (SF9650 + STO). Placed tubular sleeve separators between the 4-5 and 5-6 mixing element pairs to use for hardness samples, as well as end output. Output hardness and at 4th sample ≈ 10 points lower than other 2.
6	Flow Rate Reconfigured plumbing & loading method	560E ↓	None ↓	95 140 55 110 175 250	2.46 4.86 1.36 2.78 4.67 6.77	Slower Flow!! Reloaded due to entrapped air	a. Changed filling procedure from pressuring resin supply pot and pushing material into cylinder to (1) Evacuated resin in pot; (2) Evacuated dispenser (cylinder); pull piston back to initial (loaded) position; (3) Sucked resin in by pulling vacuum in an extra port in the cylinder; (4) Pressurized piston to expel air, and repeated (3) if necessary. b. Realigned plumbing so resin can flow by gravity (if fluid) c. Catalyst is then hand loaded (poured into its cylinder) Results showed slower flow than for RTV-577 which is more viscous!!
7	Curing Hardness	560E 560E	.3% .3%	120 175	5.10 7.60	Long time to Gel ~ 72 hrs.	Diluent/Catalyst improved flow. Slower gelling time than 577 or 577E
8	Demonstration to customer	577E	.3%	250 330	9.92 15.71	Excellent Flow	Excellent flow and gelling in ~30 minutes. Poured tile for customer to show flat nozzle and that material does not flow into cracks

TABLE 29. BREADBOARD AND PROTOTYPE TEST RESULTS (Continued)

B. 1-1/2" Mixer with 5 Element Pairs

Run	Purpose	Resin	[1]Catalyst	Pres. (psi)	Flow Rate in³/min.	Remarks	Conclusions Observations
9	Mixing & flow	577E	.2%	Not recorded due to poor mixing.		Higher flow rate. Did not mix well! No trapped air.	The larger passages (1/4") of the "BY" element reduces the mixing efficiency, while lowering pressure drop. Mix showed striations of light and dark gray mixture.
10		577E	.2%			Added 1 more pair. Improved mix, but not adequate.	Improved mixing as expected, but not sufficient to be considered "visually" adequate. However all samples showed consistent hardness (50 Durometer) even in the light colored (undercatalyzed) areas.

C. Two Stage Mixer: 3 x 1" pairs + 5 x 1-1/2" pairs (1" elements at the inlet end)

Run	Purpose	Resin	[1]Catalyst	Pres. (psi)	Flow Rate in³/min.	Remarks	Conclusions Observations
11	Mixing and flow	577E ↓	.2% ↓	100 200 250	10.65 15.2 25.6	Complete mixing. Some catalyst leading flow.	Switched to a 2 stage mixer consisting of 1" and 1-1/2" elements to maintain reasonable flow rates while improving mixing to the level obtained in the 1" mixer tests. Obtained good flow and mixing.
12	Vacuum pour 10^{-5} Torr	[2]577E	.2%	200	Not Recorded	Complete mixing.	The dispenser was mounted at ambient and connected to a bulkhead penetration into a high vacuum chamber (see Fig. 54). The vacuum chamber was evacuated to 10^{-5} torr and the mixer and dispenser output evacuated with a roughing pump. Material flow was commenced and a small pouring taken off a side port to assure air removal. Valve to chamber was opened and flow observed thru view port. Material flowed evenly, yet it seemed discontinuous as it emerged from the exit tube. It will attempt to balloon and then break off and drop into a 3" container. At the end of flow, and for the next 30 minutes material could be seen to off-gas (also evidenced on the ion pressure gage on the control panel). However, the material did not rise above the edge of the container. (See Fig. 53 for photograph of material.)

[1]Added dye to diluent
[2]used sifted alumina-silicate fibers

TABLE 29. BREADBOARD AND PROTOTYPE TEST RESULTS (Continued)

Run	Purpose	Resin	[1]Catalyst	Pres. (psi)	Flow Rate in^3/min.	Remarks	Conclusions/Observations
	D. Two Stage Mixer. Reduce elements 4 x 1-1/2" +2 x 1"						
13	Mix & Flow	[2]577E	.2%	100	---	Poor Mixing	This attempt to reduce pressure drop was unsatisfactory. Poor mixing resulted, with globs of catalyst interspersed with resin, rather than the previously observed streaking.
	The following tests were conducted using the prototype dispenser equipped with a two stage mixer as follows:						
	E. Two Stage Mixer: 4 x 1-1/2" + 3 x 1" Pairs of Elements						
14	Mix & Flow	[2]577E	.2%	100	6.4	Good Flow & Mix	By removing one 1-1/2" element pair, the mixer was shortened 3 inches with no apparent adverse mixing effect. Flow rate was lower than on previous run, but still quite acceptable. Possible reason for reduced flow rate is a different pressure drop between breadboard and prototype.
		↓	↓	200	15.7	Good Flow & Mix	Note: Various attempts had been made at measuring pressure at mixer inlet, but always resulted in a clogged gage with unreliable data.
				300	25.2		
	Dwell Time & Flow	[2]577E	.2%	100	6.2	15 Min. Dwell	These tests were a continuation of flow rate tests, with flow stopped for the time period indicated. The scatter in flow rate data is attributable to collecting small weighing samples. The tests give an indication of workability, i.e., the dispenser can be stopped for at least 15 minutes at this catalyst concentration and restarted again.
		↓	↓	100	5.5	15 Min. Dwell	
				100	6.4	15 Min. Dwell	
				100	5.1	10 Min. Dwell	
	F. Two Stage Mixer: Same as above but with 1" elements on output						No good - mixing was poor. With the low viscosity catalyst flowing thru the large mixer, it just flows thru with little if any contact with resin. This was an attempt at reducing pressure drop by steering resin before entering the high ΔP 1" elements.

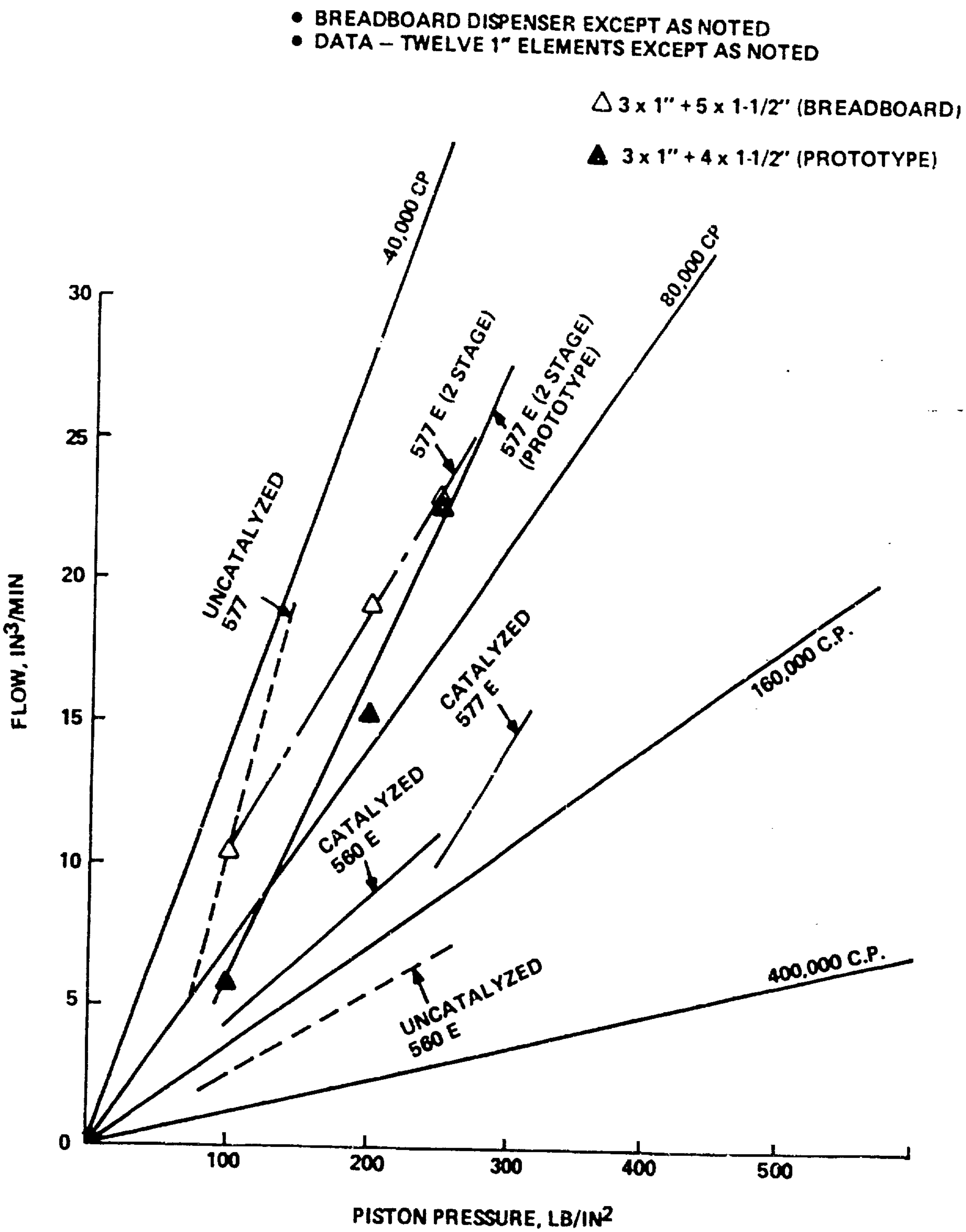


Figure 52. Static Mixer Tests

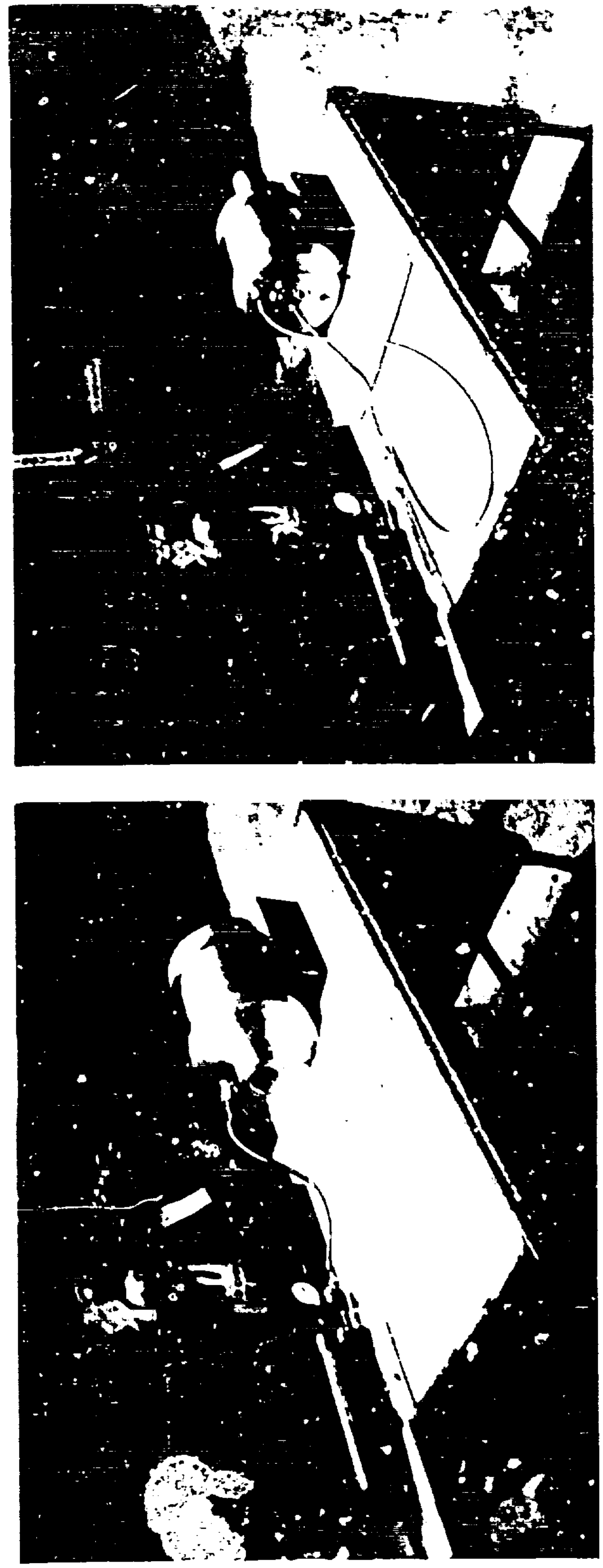
a. MIXED MATERIAL

b. SIDE VIEW OF MIXER ELEMENTS

NOTE: WHITE 577E ON SIDES IS RESULT OF REMOVAL FROM TUBE

c. END VIEW OF MIXER ELEMENTS

Figure 53. Mixing Demonstration from B/B Test Run 3 (577E with RTV-560 in Catalyst Tube)



Cyl· ·ler End

Piston Side

Figure 53A. Proof Test of Prototype Dispenser

GENERAL ELECTRIC

ENGINEERING TEST REPORT

8245 OPERATION

REPORT NO. 8245-KB-62
DATE 11-7-79

1. COMPONENT NAME DISPENSER
PART/DWG. NO.
MFR OR SUPPLIER GE-RESD

2. QUANTITY TESTED 1
QUANTITY SATISFACTORY 1
QUANTITY UNSATISFACTORY
*Indicate Serial No's in Par. 7

3. REFERENCE (Requested By)
D. Ramos - R&E

SYSTEM MODEL NO.
PROJECT NO.

4. TYPE OF TEST PROOF PRESSURE TEST

5. PREVIOUS TEST REPORT NO's (if any)

6. PURPOSE OF TEST

To subject a prototype dispenser to a hydrastatic proof pressure of 1200 +50,-0 PSIG

7. METHOD OF TEST & SUMMARY OF RESULTS

TEST A - consisted of filling the dispenser with water and a hydrastatic test pump (Richard Dudgeon Inc., Model 4A) to 1200 PSIG for 5 minutes at a rate of less than 400 PSI/min.

TEST B - consisted of filling the dispenser with water and pressurized the catalyst and resin fill ports simultaneously to 1200 PSIG for 5 minutes at a rate of less than 400 PSI/min.

RESULTS - No visible or obvious degradation or leakage was observed while the dispenser was pressurized or during the post test visible inspection.

8. CONCLUSIONS & RECOMMENDATIONS

The prototype dispenser design is structurally adequate for a proof pressure of 1200 PSIG.

9. TESTED BY L. McLaverty
REPORT PREPARED BY R. L. Bender DATE 11-7-79
APPROVED R. L. Bender DATE 11-7-79
DATE 11-8-79

DISTRIBUTION
L. McLaverty
M. Wanielista
J. Prior
D. Ramos
J. Jopski

SHEET 1 OF 1

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Figure 53B. Test Report

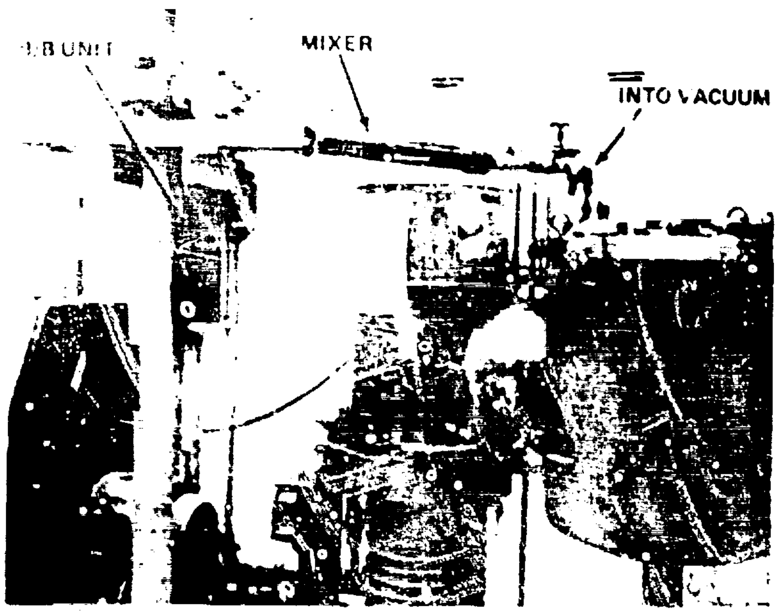


Figure 54. Vacuum Cure Demonstration, Breadboard Run 12

4.4.6 STORAGE CONTAINER ASSESSMENT

4.4.5.1 Design and Packaging Assessment

The storage container is mounted in the Payload Bay and is designed to package the pre-cured ablator sheets, the applicator with the cure-in-place ablator, emittance repair agent, and tools needed for the repair procedure.

The storage container assembly will consist of a structural box and a thermal protection system consisting of thermal blankets and active heaters. Table 30 lists estimated weights and volume. Table 31 lists repair kit weight estimates.

The storage container design concept is an enclosure where sides are made of honey-comb panels. Two separators are on the inside to provide three storage compartments. It is planned that the structural interface connection to the Orbiter fuselage will be made at the separator locations. Venting provisions are to be incorporated to avoid critical design loading from pressure changes.

The storage box overall size and general arrangement is shown in Figure 55. For operational, thermal and structural reasons the box is partitioned into three cavities. A dispenser and packages of precured ablator sheets are packaged in each cavity. The dispensers, precast ablator kits and tools are secured to remain packaged in the container until uncinched for use. Figure 56 shows an arrangement and mix of precured blocks which are held together by a light, flexible bag. Figure 57 shows an arrangement of tile intraties that can be readily detached.

The thermal protection system to maintain 100°F ± 10° inside the storage container is accomplished by using a multi-layer insulation (MLI) blanket on the outside of the structural box and resistance wire heaters with thermocouples on the inside surface.

The internal heaters are then silicone rubber sheets with imbedded wires. These are attached to the inside wall of the box to give a uniform heat to the repair kit. The heaters are controlled by thermostats to be located by analysis and tests.

TABLE 30. STORAGE CONTAINER WEIGHT ESTIMATE

Box Sandwich Area (No Cover)				
Front	26" x 38" = 988 in^2	6.86 ft^2		
Back	26" x 38" = 988	6.86		
Ends	(26 x 21)2 = 1092	7.58		
Bottom	21 x 38 = 798	5.54		
		26.84		
Honeycomb Sandwich				18.5
Outerskin 8 mils.	(.0144 lb/ft^2/mil) 26.84		= 3.1	
Innerskin 4 mils.	(.0144 lb/ft^2/mil) 26.84		= 1.5	
Core - GL. Fabric	0.2 (26.84)		= 5.4	
Bond - 2 pls.	0.2 (26.84)		= 5.4	
Stiff. & Reinfmt. @ 20%			= 3.1	
Handholds & Tiedowns				4.5
Interface Attachment				2.0
Thermal Control				
MLI Blanket			5.0	7.5
Heaters & Harness			2.0	
Velcro Attachmt.			0.5	
Block and Tile Bags & Lanyards				2.5
			Total	35 lbs

TABLE 31. REPAIR KIT WEIGHT ESTIMATE

Item	Wt, lb
1) Precured Ablator (ESM 1004 AP) $3.75\ ft^3$ @ $35\ lb/ft^3$	132.0
2) Cure-in-place Ablator (RTV 577E) $1200\ in^3$ @ $69.2\ lb/ft^3$	48.0
3) Emittance Agent (GFE)	20.0
4) Dispensers 3 @ 35 lb	105.0
5) Tools	1.0
6) Thermal Control & Connector	2.0
7) Stockage Container	35.0
	343

NOTES:

- Item (1) can be reduced by lower ρ ESM for sublayers
- Item (2) can be reduced by accounting for foamed density ($\sim 50\ lb/ft^3$) expected when applied

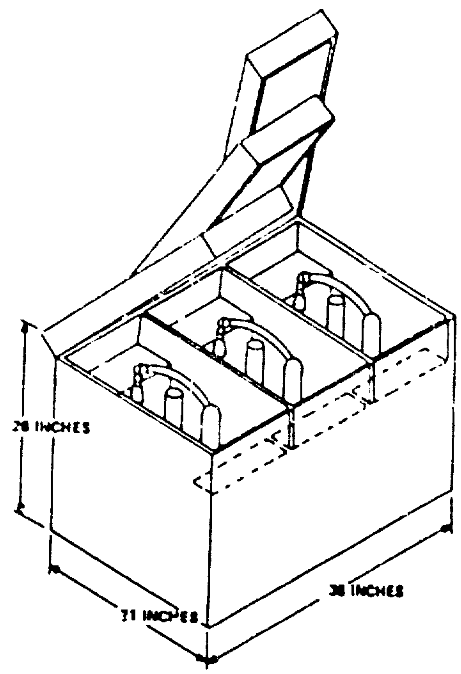


Figure 55. Storage Container

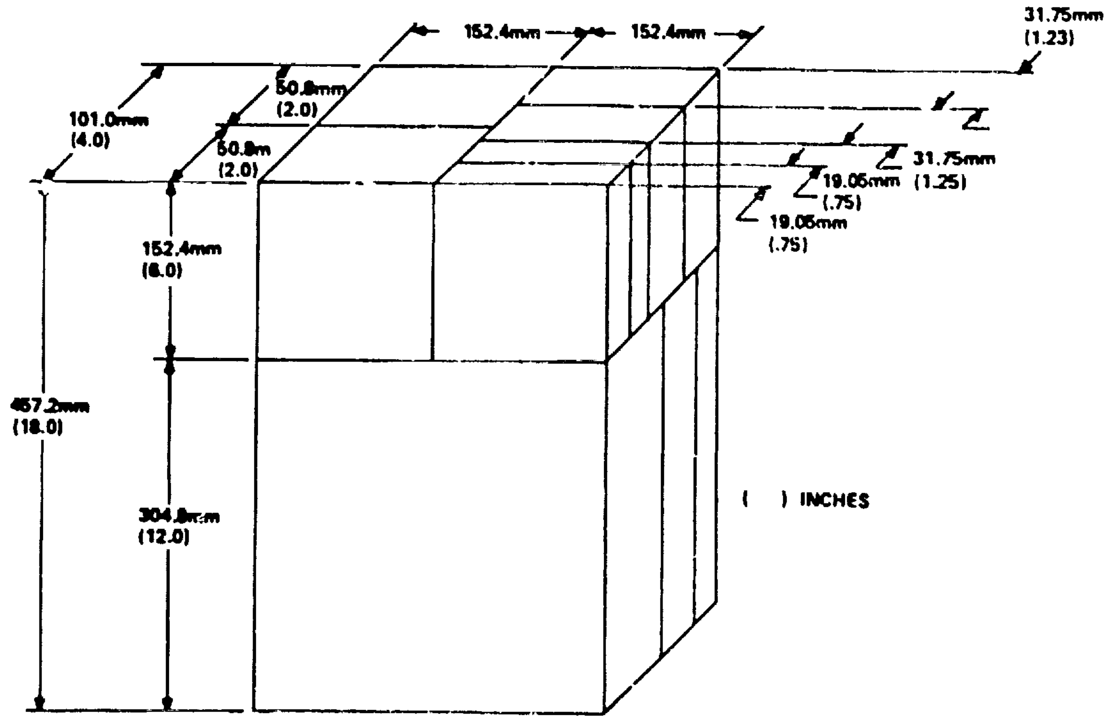


Figure 56. Precured Block and Tile Package

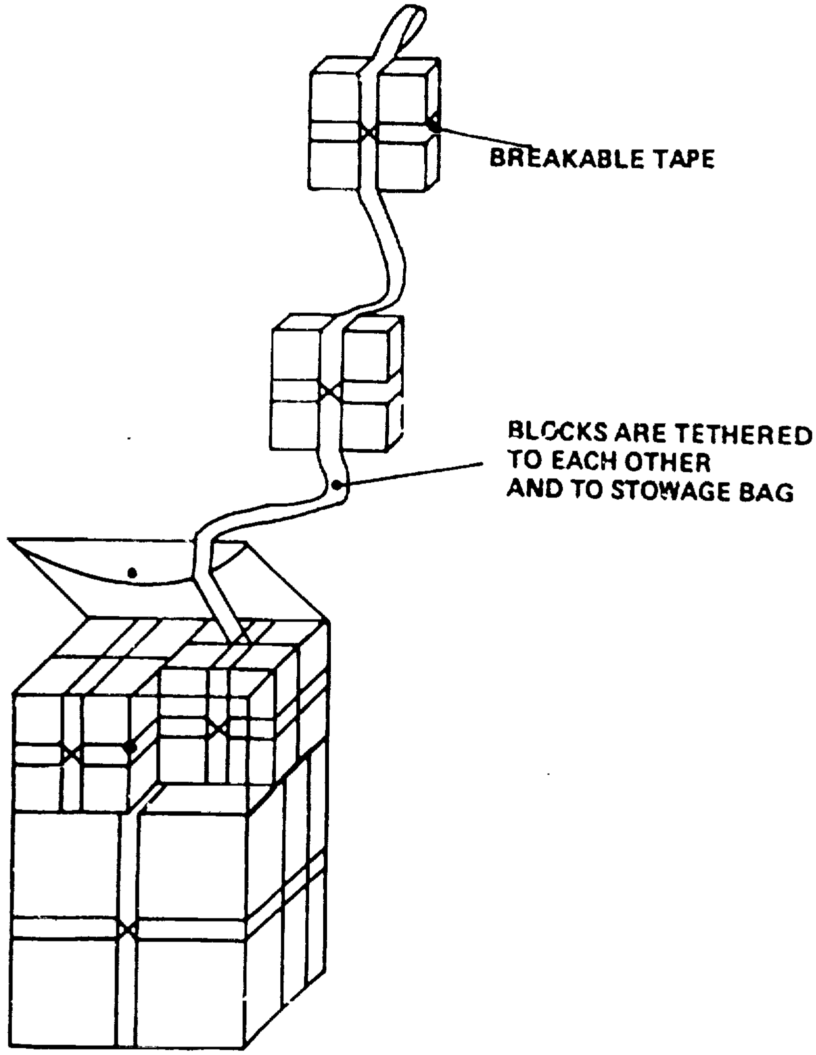


Figure 57. Precured Block Stowage Bag

Thermal Control Assessment

The utilization of the repair materials, especially the cure-in-place material, requires controlled temperatures for adequate working life and to assure adequate cure and performance. The general approach to this problem was to:

a. Store in the storage containers at sufficiently high temperature to allow some cooling while performing subsequent operations. For initial purposes the storage temperature was established as 100°F ±10.

b. Minimize temperature decay during EVA by passive techniques (no power available).

c. Provide adequate temperature in repair area by initial temperature of the inserted material, spacecraft attitude control, and structural heat sources.

These thermal control concepts are summarized in Figure 58 and discussed in the following sections:

Storage Container Control — The thermal environment experienced by the storage container can range from a direct view of space (T_{sink} = 0°R) to direct solar exposure resulting from certain orbit/vehicle orientation combinations.

Maintenance of 100°F ±10° in the storage container is readily accomplished by use of thermostatically controlled resistance wire heaters covered with an insulating blanket. The insulating blanket can be either: 1) a multilayer radiation barrier insulation type, or 2) a low density, low thermal conductivity foamed or fibrous material type. Numerous candidate insulative materials exist. Two that have a combination of both low density and low thermal conductivity are Nomex felt and Litaflex. Thermophysical properties of these candidate materials are summarized in Table 32. An alternative low weight approach is to employ a multilayer radiation barrier insulation. Typical effective emissivity of an MLI is 0.02.

View factors from the storage container surfaces to space were estimated and determined to range from 0.17 to 0.23 for a container location on the floor at the end of the payload bay. Cold case heater power requirements were calculated, Table 33, to hold 100°F for the several insulation concepts considered, using a view factor of 0.23. An insulation thickness of one inch was employed for the Litaflex and Nomex. Doubling the insulation thickness would reduce the heater power requirement by only about 30%. For the multilayer radiation barrier type insulation, an effective emissivity of 0.02 was employed with a surface emissivity looking at space of 0.9. The unit weight of these insulation concepts (lbs/ft^2) is also summarized in Table 33. Note that the Litaflex concept would appear to be the lightest although it requires the larger power consumption; the heavier MLI results in the lowest power consumption.

For the hot case, a direct exposure to incident solar radiation with surface characteristics of $\alpha = 0.36$ and $\epsilon = 0.9$, results in container surface temperatures approaching 350°F if the view factor to space is limited to 0.23. If the view factor to space can be increased to 1.0, the maximum surface temperature is limited to 100°F, although the heater power requirement for the cold case also increases. If the view factor cannot be increased, orbiter attitude constraints will be necessary.

Consideration must also be given to conductive insolation of the storage container from its support structure.

EVA Thermal Control — The thermal environment experienced by the EVA Kit and dispenser gun can range from a direct view of space (T_{sink} = 0°R) to direct solar exposure resulting from certain orbit/vehicle orientation combinations for periods of time up to 3 hours in duration.

An initial evaluation has been made of a spherical kit with a volume of one cubic foot and an average material density of 60 lb/ft^3 (combination of ablator and metal parts). Employing a Litaflex insulation thickness of 0.5 inch limits the bulk cool down to 20°F Δt in a one hour time period. Adding a low emissivity surface and thicker insulation to the EVA kit would further delay the cool down. For example, reducing the surface emissivity to 0.2 reduces the cool down to about 8°F/hr.

The dispenser gun cooling characteristics are similar to the spherical kit described above. However, the hose/nozzle area, where the ablator material volume is small relative to the radiating surface area (say a 1 inch diameter hose with 1-inch of insulation surrounding, Figure 59) presents a more serious cooling problem. If the ablator material remains stationary in the hose for 1/4 to 1/2 hour, it will cool from an initial temperature of 90 to 40°F. This may be unacceptable and may require clearning the hose and nozzle at 10-20 min intervals.

Tile Repair Area Thermal Control

The thermal environment experienced by the repaired area is to be restricted by vehicle attitude control management. On the cold side, the effective sink temperature can be limited to 20-30°F; on the hot side to 90-100°F. The cooling times of the repaired areas for the cold case are dependent on the thickness of the repaired tile and its initial temperature. The hot case provides more acceptable curing temperature for the repaired areas, but an evaluation of the colder structure areas of application must be made.

Bulk cooling times were calculated for several repaired tile thicknesses and several initial temperatures. Calculations were performed for an effective sink temperature of 30°F, a final bulk tile temperature of 40°F and an emissivity-view factor ($F_e F_a$) of 1.0. Results are summarized in Table 34. Note the increased cooling times resulting from the higher initial temperatures and increased tile thicknesses. As the curing temperature-time requirements of the ablator and bond are evolved, the above analysis can be refined with some reference transient calculations. If required, thermal protection blankets can be provided for increased temperatures during cure. For instance, emissivity control can be provided by the same plastic used for mold line contouring.

TABLE 32. THERMOPHYSICAL PROPERTIES OF NOMEX FELT & LITAFLEX

Material	Source	Characteristics	Density	Thermal Conductivity (@ 100°F)	
			Lb/Ft^3	($Btu/Ft\ Sec°F \times 10^5$) 1 atm	10^{-4} atm
LITAFLEX	Rex Asbest-warke Germany	Asbestos Form Soft, Compressible	1 - 6	0.75	0.45
NOMEX FELT	Globe Albany	Aromatic Polyamide	5.2	0.65	0.16

TABLE 33. STORAGE CONTAINER INSULATION REQUIREMENT SUMMARY

Insulation Concept	Thickness (in.)	Weight (psf)	Heater Power Requirement	
			(watts/ft^2)	watts
MLI		0.15-.2	0.9	20
NOMEX FELT	1	0.43	3.0	66
LITAFLEX (E = .9)	1	0.08	5.3	117
(G = .27)	1	0.08*	0.9	53

*Does not include low emissivity foil coating weight.

TABLE 34. BULK COOLING TIMES

Average Initial Temperature of ESM (°F.)	ESM Thickness (Inches)		
	0.75	1.25	2.0
	Bulk Cool Down Time to 40°F. (Minutes) T_{sink} = 30°F, $F_\epsilon F_a$ = 1.0		
100	32	54	86
80	31	39	77
60	28	35	69

			COLD CONDITION	HOT CONDITION
• STORAGE	DURATION (MIN)	REPAIR MTL TEMP (°F) ← POWER AVAILABLE		
	∞	100 ± 10	4° K SINK	β = 0° , h = 100 - 300 NMI
• EVA	60	100	0°K	90°F SINK
BAG	↓	↓	↓	↓
GUN				
HOSE	60	70	0°K	90°F SINK
• REPAIR AREA	18 HRS	> 40°F GOAL FOR ADEQUATE CURE	20-30 F SINK	90-100°F SINK
			BY VEHICLE ATTITUDE MANAGEMENT	

Figure 58. Thermal Control Ground Rules

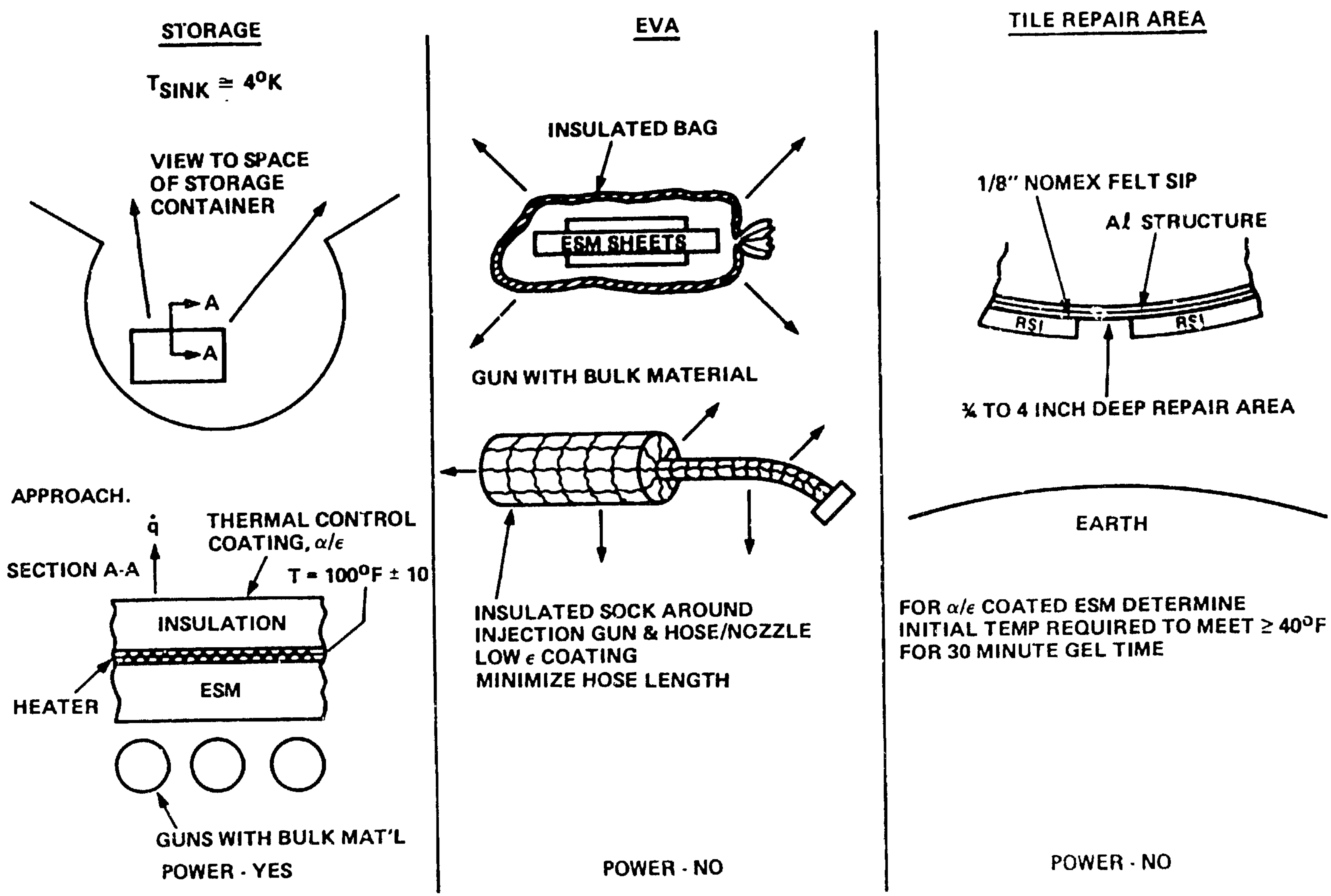


Figure 59. Thermal Control Approach

4.4.7 OPERATIONAL ASPECTS

The repair operations are based on:

a. Using cure-in-place ablator for repairing all areas less than 3/4" thick
b. Using cured-in-place ablator for repairing all single missing tiles or single missing tiles with a section of an abutting tile missing
c. Using pre-cured ablator for all other repairs (large areas) with the cure-in place material used as the bond

The storage container will have 3.75 ft^3 of pre-cured ablator packaged in eight 16.5 pound packages, along with three insulated dispensers, each with 400 in^3 of cure-in-place material. A single multifunctional tool will also be in the kit, and sufficient sheets of plastic for cure-in-place ablator leveling to the mold line. Figure 60 shows a schematic of the repair kit on the work station.

The storage container requires thermal monitoring prior to use in order to have the repair material at 100°F. This is most important just prior to use of the material. The heated storage will maintain the flexibility of the pre-cured material and keep the cure in place resin and catalyst fluid and at the proper temperature for the required cure rate. The frequency of this monitoring is TBD. The astronaut will initially turn heater power on when the PLB doors are opened for space craft thermal control.

All the repair material is stored in the container and the applicator/mixers have the thermal insulation required for use during the repair mission. When the pre-cured tile kits are removed from the storage container, they will be placed in an insulated storage unit (RMETB) along with the multifunctional tool and the plastic film. The loading of the WS with these repair items occurs before the astronaut donns the MMU/WS.

Cure In Place Ablator

Unit Volume - The requirement for 1,080 in^3 of material will be met through the use of three 400 in^3 units. This package volume will achieve a reasonable balance in the work station between cured-in-place ablator and pre-cured ablator, while being consistent with the 85-pound limit established in the Design Reference Mission document. In this volume configuration, the following weights accrue for a maximum repair mission: For small areas repair missions, some or all of the pre-cured ablator can be omitted.

Item	Weight, Pounds
Cure-in-place ablator material	16
Mixer/dispenser (empty)	26
Tools and miscellaneous supplies	2
2 Pre-cured ablator packages	33
Total	77

Dispenser Activation - Three simple on/off type valves activate the dispenser unit. The valves will have a locking safety feature to be determined later. As shown in Figure 60, the valves are located on the top of the dispenser unit and readily reachable by the astronaut's right hand. The resin and catalysts valves will be turned on first, and then the air valve. When the air valve is turned on, the two pistons move down and proportion the resin and catalyst into the mixer sections, through the delivery hose to the dispensing nozzle. No material can leave the dispensing nozzle unless the safety device (TBD) is activated and the handle depressed. All the valves will activate with simple wrist action type motion.

After the applicator/mixer has been activated and prior to the deposition of the material to the repair area, a small quantity of the material will be discharged to the scrap bag to clear the gun of voids and provide a sample for later examination of cure.

Ablator Flow Characteristics - The ablator material in the catalyzed condition is a very viscous (1.2 million centipoise) material. In this heavily bodied form, the cohesive forces within the material are extremely high and the material is a naturally very "sticky" substance. The combination of high cohesive forces and very sticky surface provides a material which will stop moving in the zero 'g' space environment as soon as the delivery nozzle is turned off. The high viscosity of the material will prevent it from being forced into the areas between tiles and also provide a scouring action at the vehicle/cured-in-place ablator, which will insure the good wetting required to optimize the bond strength.

Ablator Flow Rate - The dispenser unit has been sized to provide a maximum flow rate of 20 in^3 per minute and under these conditions a 6 X 6 X 2-inch cavity could be filled in about [illegible] minutes. This flow rate was selected to provide a reasonable balance between the rate useable in filling a single tile void, which is fairly high, and applying the bedding base required to bond a pre-cured ablator in place in either a void or over a previously installed pre-cured ablator. Fairly slow rates will also be used when partially missing tiles or edges around pre-cured ablator are filled. The flow rate is controllable by astronaut positioning of the trigger type dispensing valve.

The dispenser is expected to remain operational for 60 minutes. Two things could prevent this; material cure and blocking of the mixer/hose assembly or excessively low temperature and high viscosity condition. The first condition is expected to be prevented by catalyst concentration optimization and later by adequate insulation of the hose/nozzle elements which have very low heat capability. If either of the solutions are not possible, it may be necessary to clear the mixer/hose assembly by discharging material into the waste bag once or twice in a 60 minute period.

Cure Assurance - The resin/catalyst system represents a white and black material. When the two materials are properly mixed, they are a medium grey in color and generally free of striations. This color feature provides the astronaut with continual assurance that the deposited material has been catalyzed, is properly mixed, and will effectively cure. The sample placed in the scrap container at the beginning of each gun start up will further provide a physical demonstration of cure.

Pre-cured Ablator - Subkits of pre-cured ablator tiles have been defined as an assortment of 3/4, 1 1/4, and 2 inch thicknesses. There are six large area repair subkits suitable for large and deep areas, and two small area repair subkits. With this assortment, the astronaut will be able to fill most areas with no more than two layers of tiles plus the adhesive bond, and still meet the outer mold line restoration requirement of ± 1/4 inch.

Larger, prescored slabs of ESM material were considered, but it was determined that a slab larger than 12 x 12 inches would be excessively difficult to handle at the repair site.

The tiles are tethered together and after they have been positioned, the tether can be withdrawn.

Repair Techniques

All Areas

- A visual inspection will be made of the damaged areas and abutting tile to determine if any loose pieces exist.
- The damaged area and abutting tiles will be gently felt for loose points or nearly destroyed bonds. Where loose pieces or nearly loose pieces exist, they will be picked up with the aid of the sticky surface tool, Figure 61.

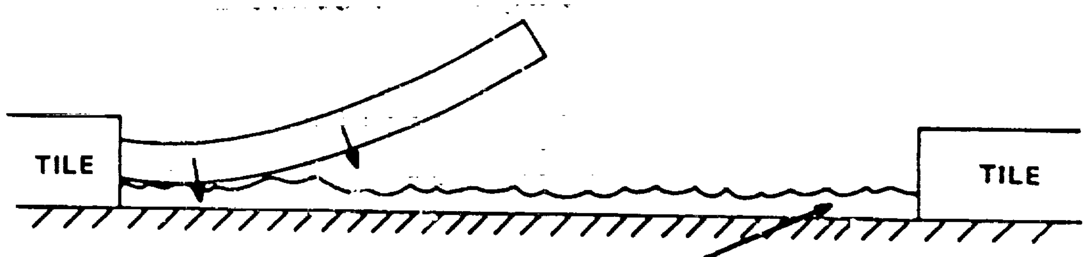
When the repair area has been cleared of major tile particles, the applicator/mixer nozzle will be picked up and the spring loaded variable flow valve activated by removing the safety device (TBD, probably a pull ring). The flared dispensing nozzle will then be positioned in the far corner of the missing tile area and the handle depressed. As the material flows from the nozzle, the nozzle tip will remain within the deposited material and will be gradually drawn across the void with a slight upward motion, Figure 62. This withdrawal procedure is aimed at preventing void enclusion, which would collapse upon re-entry. If the area being repaired is wider than the dispensing nozzle, the nozzle will be slowly directed from side to side so as to completely fill the cavity in front of it before moving back (Figure 63). In this manner, the resulting installation will resemble a loaf of bread. During the crew training, operator efficiency should improve to the point where the repaired void will require no additional operations following the cavity filling. The smooth flowing characteristics of the cured in place ablator tests to date suggest this conclusion. If, however, an overfill condition or an unevenly filled condition exists, a roll of plastic film will be removed from the insulated storage unit and unrolled across the face of the repaired cavity. Due to the very sticky nature of the cure in place ablutor, the plastic will be "grabbed" by the surface. The back of the multi-functional tool (or back of gloved hand) will then be used to level the surface and contour any extra material across the surface of adjacent tiles. The plastic film (which can be used for emissivity control) will be left on the surface. In cases where a significant amount of excess material has been deposited, the front edge of the multi-functional tool will be used to scoop the material up and deposit it in the scrap bag, and the bag interior used to wipe the tool clean.

The extended piston of the applicator mixer is graduated into four units of volume. In this manner, the astronaut will continually know the amount of material left within the container. No repair should be initiated unless there is sufficient material within the container to complete the work.

Precured Tile Repair Technique

The tile thickness required for each repair area will be known from location of the repair and the width and length of the repair roughly determined. The proper thickness tile will be selected from the insulated storage area and fractured along the pre-scored lines and dry fitted into the repair area. Tiles representing the total build up will be sized at this time and then returned to insulated storage. The dispenser applicator will then be turned on with the nozzle in the corner of the area to be repaired. The nozzle will be smoothly drawn across the area to be repaired and a ribbon of material deposited. Where vehicle contours are encountered, extra material will be deposited in lower areas so that as flat a surface as possible is generated for the bedding of the pre-cured tile. The nozzle of the applicator will then be used to smooth out the ribbons of cure in place bond. Being generally smooth is all that is required.

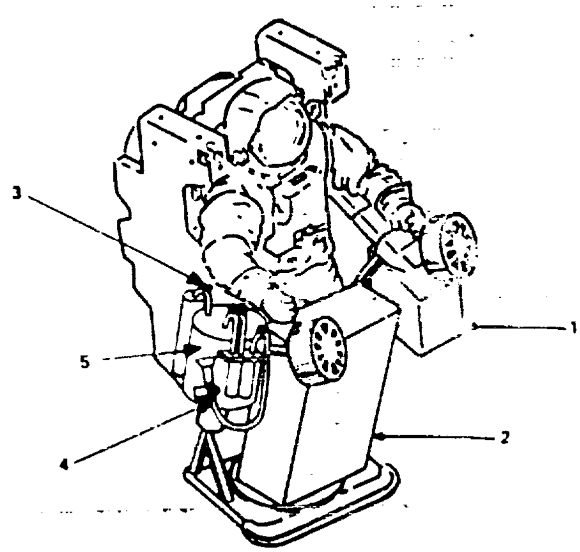
The presized tiles for the first layer would be removed from the heated storage and the first corner tile installed. For installation, the tile is curved back and installed as shown in the following sketch.



PRE-CURE TILE INSTALLATION

Tests have shown that the material flows well when 2 to 4 pound force is applied to the area of the tile that is being applied. A slight wiggling motion also helps bed the tile and eliminate the inclusion of voids.

After all the tiles in the first layer have been installed, a second layer of bedding ablator will be applied in the same manner as the first layer if a second pre-cured ablator is to be used or if the cavity requires additional cure in place material to meet the thickness dimension. Additional tiles will be added in the manner of the first layer if successive thicknesses are required. If this is the case, then the thinnest tile will be placed on the bottom of the cavity, thus affording greater ablation depth before encountering a bond line. If not, the perimeter of the repair area, where voids exist between the pre-cured ablator and original tiles, shall be filled by inserting the cure-in-place ablator nozzle into the void and slowly drawing the nozzle across the void, depositing the required ablator thickness.



1. Insulated storage for precured ablator, tool and plastic film (GFE) (RMETB)
2. Scrap bag
3. Air, Resin and Catalyst valve
4. Four foot hose with volume control valve and special nozzle on dispenser
5. Dispenser

Figure 60. Repair Mission Equipment

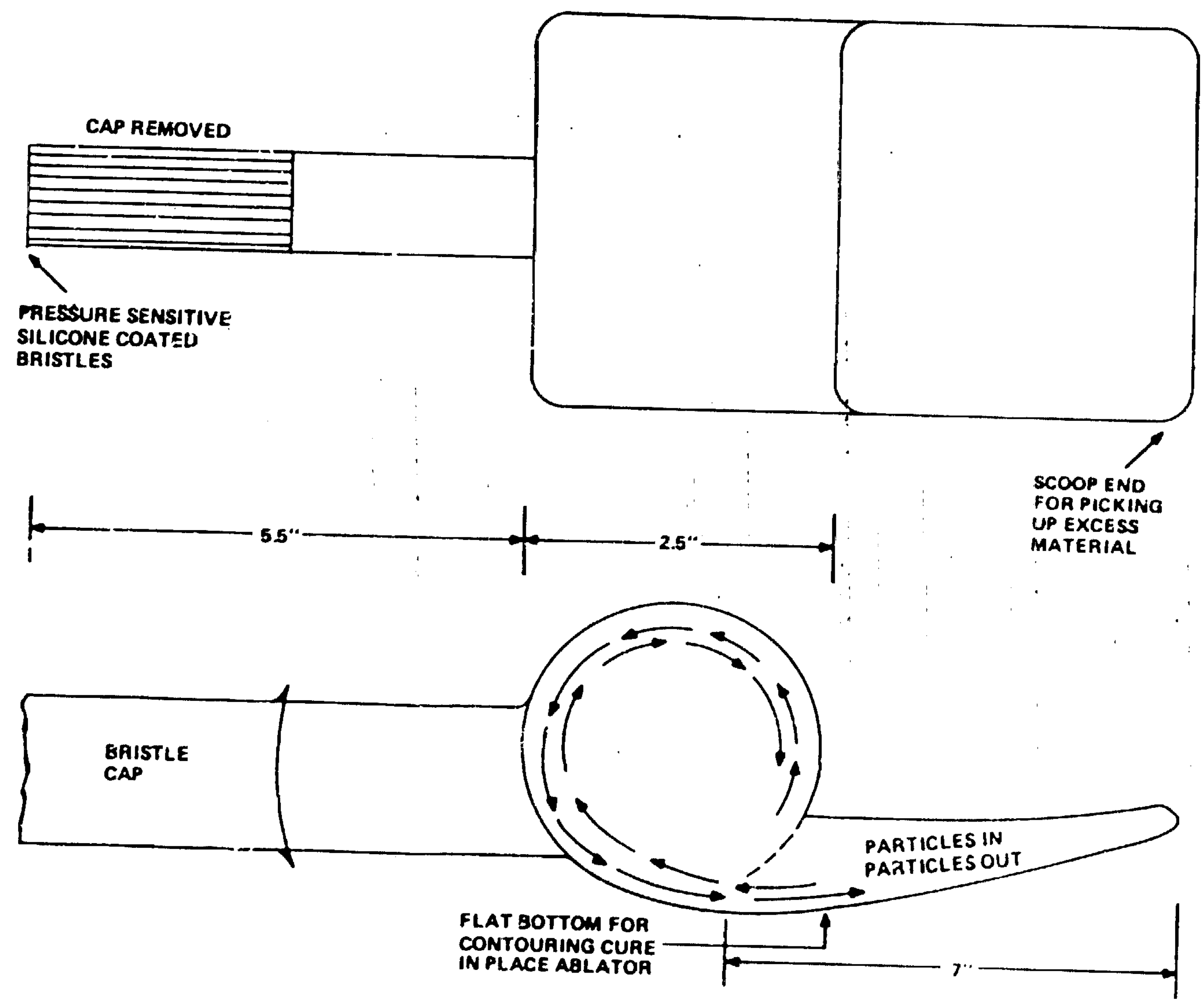


Figure 61. Multifunctional Tool

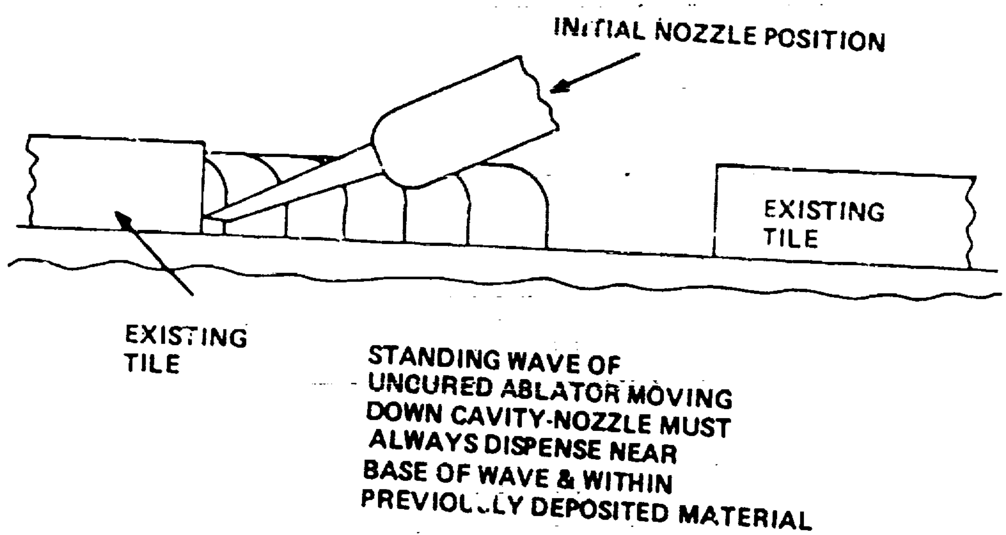


Figure 62. Top View Fill Technique

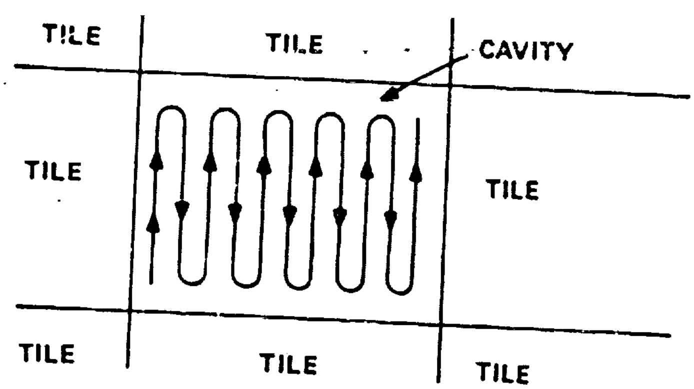


Figure 63. Side View Fill Technique

5.0 RECOMMENDATIONS

- Utilize the following specific solutions:
  - ESM L004 AP precured ablator
  - RTV-577E Cure-in-place ablator/adhesive
  - A 400 cubic inch dispenser similar to the prototype unit
- Proceed with design, fabrication and flight of the tile repair kit as conceptually devised by JSC.